

Monitoring of Layered Uranium Tailings
- Phase I

DSS File #26SQ.23241-4-1679
Contract No. OSQ84-00085

A Research Report prepared for:

The National Uranium Tailings Program
Canada Centre for Mineral and Energy Technology
Energy, Mines and Resources Canada
555 Booth Street
Ottawa, Ontario
K1A 0G1

by

Knight and Piesold Ltd.,
1350 United Kingdom Building
409 Granville Street
Vancouver, B.C.
V6C 1T2
Canada

In association with

SENEC Consultants Ltd.
499 McNicoll Avenue
Willowdale, Ontario
Canada M2H 2C9

Department Of Civil Engineering
University Of Saskatchewan
Saskatoon, Saskatchewan
Canada S7N 0W0

Saskatchewan Research Council
30 Campus Drive
Saskatoon, Saskatchewan
Canada S7N 0X1

May, 1985

289 pp

MICROMEDIA

OCT 11 1985

ACKNOWLEDGEMENT

The assistance and cooperation of the staff and personnel of the Key Lake Mining Corporation, in making this research project possible is gratefully acknowledged.

MONITORING OF LAYERED URANIUM TAILINGS - PHASE I

DSS FILE NO. 265Q.23241-4-1679

CONTRACT NO. OSQ84-00085

TABLE OF CONTENTS

	<u>Page</u>
SECTION 1.0 SUMMARY	1-1
SECTION 2.0 INTRODUCTION	2-1
2.1 OBJECTIVES AND TERMS OF REFERENCE	2-1
2.2 DESIGN FEATURES OF THE TAILINGS STORAGE FACILITY	2-2
2.3 MONITORING INSTALLATIONS AND STUDY OUTLINE	2-3
2.4 BRIEF HISTORY OF DEPOSITION	2-5
SECTION 3.0 ACCUMULATION METHODS	3-1
3.1 GENERAL	3-1
3.2 CONTINUOUS MONITORING EQUIPMENT	3-1
3.2.1 Temperature Sensors - Site A	3-3
3.2.2 Relative Humidity Sensor	3-4
3.2.3 Insolation	3-5
3.2.4 Precipitation	3-5
3.2.5 Wind Speed	3-5
3.2.6 Seepage Flow	3-6
3.2.7 Pore Pressure Transducers	3-6
3.3 MOISTURE DENSITY GAUGE	3-8
3.4 RADIATION MEASUREMENTS	3-10
3.4.1 Gamma Radiation	3-10



3.4.2	Radon Exhalation	3-10
3.4.3	Subsequent Radon Measurements	3-12
3.5	VISUAL OBSERVATIONS	3-12
3.6	WATER SAMPLING	3-12
3.7	CORE SAMPLING	3-13
3.8	THERMOGRAVIMETRIC ANALYSIS	3-14
3.9	MISCELLANEOUS MEASUREMENTS	3-14
3.9.1	Temperature Sensors - Site B	3-14
3.9.2	Site A Phreatic Surface	3-15
SECTION 4.0	ATMOSPHERIC DATA	4-1
4.1	OBJECTIVES	4-1
4.2	TEMPERATURE	4-2
4.3	PRECIPITATION	4-2
4.4	RELATIVE HUMIDITY	4-2
4.5	WIND RUN	4-3
4.6	SOLAR INSOLATION	4-3
SECTION 5.0	TAILINGS PHYSICAL DATA	5-1
5.1	SURFACE CONDITIONS	5-1
5.2	PORE PRESSURE MONITORING	5-1
5.3	TEMPERATURE PROFILES AND FROST PENETRATION	5-2
5.4	SEEPAGE QUANTITIES	5-3
5.5	THERMOGRAVIMETRIC ANALYSIS (T.G.A.)	5-4
5.6	MOISTURE DENSITY READINGS	5-5
5.7	RADIATION MEASUREMENTS	5-7
5.7.1	Gamma Radiation	5-7
5.7.2	Radon Exhalation	5-8
5.7.3	Subsequent Radon Measurements	5-14
5.8	GEOTECHNICAL PARAMETERS	5-14
5.8.1	General	5-14



Knight and Piessold Ltd.

CONSULTING ENGINEERS

5.8.2	Specific Gravity	5-15
5.8.3	Particle Size Distribution	5-16
5.8.4	Density Results	5-16
5.8.5	Consolidation Test Results	5-17
5.8.6	Settling and Air-Drying Tests	5-18
5.8.7	Saturated Permeability Tests	5-18
5.8.8	Unsaturated Permeability	5-19
SECTION 6.0	OBSERVED TAILINGS BEHAVIOUR	6-1
6.1	TAILINGS DEPOSITION	6-1
6.2	CONSOLIDATION AND DRAINAGE	6-2
6.3	WATER BALANCE	6-5
SECTION 7.0	CHEMICAL AND MINERALOGICAL PROPERTIES - TAILINGS SOLIDS	7-1
7.1	PROGRAM OUTLINE	7-1
7.2	CHEMICAL AND RADIOLOGICAL CHARACTERISTICS	7-1
7.3	MINERALOGY	7-4
7.3.1	Major Minerals Identified	7-4
7.3.2	Heavy Metals	7-6
7.3.3	Summation	7-8
SECTION 8.0	CHEMISTRY - TAILINGS LIQUIDS	8-1
8.1	PROGRAM OUTLINE	8-1
8.2	PRESENTATION OF RESULTS	8-1
8.2.1	Tailings Influent	8-1
8.2.2	Tailings Pond Effluent (Surface Runoff)	8-3
8.2.3	Tailings Pond Seepage	8-3
8.2.4	Tailings Porewaters	8-3
8.2.5	Leaching Studies	8-4



Association
of Consulting
Engineers
of Canada

Association
des Ingénieurs-
Conseils
du Canada

8.3	DISCUSSION OF RESULTS	8-5
8.3.1	General	8-5
8.3.2	Arsenic	8-6
8.3.3	Chromium, Molybdenum and Tungsten	8-7
8.3.4	Nickel, Lead and Zinc	8-7
8.3.5	Radionuclides	8-8
8.3.6	Uranium	8-9
8.3.7	Organic Content	8-10
SECTION 9.0	GEOCHEMICAL CONTROLS	9-1
9.1	INTRODUCTION	9-1
9.2	PRIMARY GEOCHEMICAL CONTROL	9-2
9.2.1	pH Effects	9-4
9.2.2	Ionic Strength	9-5
9.2.3	Oxidation - Reduction Potential (Eh)	9-5
9.3	GEOCHEMICAL MODELS	9-6
9.3.1	Overview of Equilibrium	9-6
9.3.2	Arsenic	9-9
9.3.3	Molybdenum	9-11
9.3.4	Nickel	9-13
9.3.5	Uranium	9-14
SECTION 10.0	SEEPAGE MODELLING	10-1
10.1	INTRODUCTION	10-1
10.2	OPERATIONAL PHASE	10-2
10.2.1	General	10-2
10.2.2	Vertical Seepage Model, Case 1	10-3
10.2.3	Vertical Seepage Model, Case 2	10-5



10.2.4 Anisotropic Model	10-6
10.3 LONG TERM PHASE	10-7
10.3.1 General	10-7
10.3.2 Vertical Seepage Model, Case 1	10-8
10.3.3 Vertical Seepage Model, Case 2	10-8
10.4 SUMMARY OF SEEPAGE MODELLING	10-9
SECTION 11.0 RECOMMENDED SCOPE OF WORK FOR PHASE II	11-1
11.1 OBJECTIVES	11-1
11.2 SCOPE OF WORK	11-2
11.3 SCHEDULE FOR PHASE II	11-4

TABLES

Table 3.1	follows page 3-13
Table 4.1	follows page 4-2
Table 5.1	follows page 5-1
Table 5.2	follows page 5-6
Table 5.3	follows page 5-7
Table 5.4	follows page 5-8
Table 5.5	follows page 5-17
Table 6.1	follows page 6-5
Table 7.1	follows page 7-1
Table 7.2	follows page 7-4
Table 8.1	follows page 8-1
Tables 8.2 to 8.3	follows page 8-3
Table 8.4	follows page 8-4
Tables 8.5 to 8.7	follows page 8-5
Table 9.1	follows page 9-3



Knight and Piesold Ltd.

CONSULTING ENGINEERS

Table	9.2	follows page 9-4
Table	9.3	follows page 9-9
Tables	9.4 and 9.5	follows page 9-11
Table	9.6	follows page 9-13
Table	9.7	follows page 9-15
Table	9.8	follows page 9-2

FIGURES

Figure	2.1 and 2.2	follows page 2-3
Figure	2.3	follows page 2-4
Figure	3.1	follows page 3-2
Figures	3.2 and 3.3	follows page 3-6
Figure	3.4	follows page 3-8
Figure	3.5	follows page 3-13
Figures	4.1 and 4.2	follows page 4-2
Figures	4.3 to 4.6	follows page 4-3
Figures	5.1 to 5.5	follows page 5-1
Figure	5.6 and 5.7	follows page 5-2
Figure	5.8	follows page 5-3
Figure	5.9	follows page 5-10
Figure	5.10	follows page 5-11
Figure	5.11	follows page 5-15
Figures	5.12 and 5.13	follows page 5-16
Figure	5.14	follows page 5-17
Figures	5.15 and 5.16	follows page 5-19
Figure	7.1	follows page 7-1
Figure	10.1	follows page 10-3
Figures	10.2 and 10.3	follows page 10-4
Figure	10.4	follows page 10-6
Figures	10.5 and 10.6	follows page 10-8



Association
of Consulting
Engineers
of Canada

Association
des Ingénieurs-
Conseils
du Canada

APPENDICES

- | | |
|------------|---|
| Appendix A | Terms of Reference |
| | AI Original Statement of Work |
| | AI Additional Work and Contract Amendments |
| Appendix B | Data Tables. Figures B1, B2, Tables B1 to B38 |
| Appendix C | Excerpts from Test work Carried Out By Saskatchewan Research Council. |
| Appendix D | Report On Thermogravimetric Analysis by B.C. Research |

PHOTOGRAPHS

- Photograph No. 1 follows page 2-4

Aerial view of tailings facility looking North. (March, 1985)

- Photograph No. 2 follows page 2-4

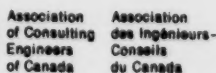
Monitoring hut at Site A. Stevens screen, pyranometer and rain gauge at left. Site A with standpipes and moisture density access pipes at right.

- Photograph No. 3 follows page 3-5

Seepage flow meter and water sampling pipework inside monitoring hut.

- Photograph No. 4 follows page 3-5

Gamma radiation instrument in use 1 metre above frozen tailings surface at Site A.



Photograph No. 5

follows page 3-9

Site A. Moisture density gauge with probe down access tube. Standpipe piezometer at left, soil temperature mast at right.

Photograph No. 6

follows page 3-9

Site A. Radon accumulator at left. Ice thickness approximately 350 mm with core sampler in place for sample extraction.

Photograph No. 7

follows page 3-13

Temperature monitor at Site B registering soil temperature 0.2 m above filter blanket on March 9.

Photograph No. 8

follows page 3-13

Access scaffolding at Site B with moisture density access tubes (white caps) and soil temperature mast.



MONITORING OF LAYERED URANIUM TAILINGS - PHASE I

DSS FILE NO. 26SQ.23241-4-1679

CONTRACT NO. OSQ84-00085

SECTION 1.0 - SUMMARY

A monitoring study has been carried out to obtain detailed information on the mineralogically-complex uranium tailings at the Key Lake operations in Northern Saskatchewan. The tailings are deposited using the sub-aerial method in a tailings facility that incorporates a filter blanket and underseal over the entire area and a pervious embankment to decant surface water and to prevent any ponding on the exposed tailings beaches. These features have been designed to achieve full consolidation and the elimination of seepage from the tailings while the mine is in operation. Approval to commence the monitoring study was obtained on July 3rd, 1984.

The tailings storage facility incorporates instrumentation to monitor the overall performance of the facility. This instrumentation is essentially external to the tailings itself and monitors the facility on a macro-scale. However, the opportunity existed to determine in detail the nature and behaviour of the actual tailings during deposition, and to generate information required for long-term predictions. This gave rise to this monitoring study under the auspices of the National Uranium Tailings Program. The results of Phase I of the study are presented in this report.

Monitoring installations for the study include two instrumented test sites within the tailings facility. One of the two sites contains a separate underdrain and seepage recovery system with automatic data logging equipment to record atmospheric data and tailings physical data. Continuous recording has been supplemented with site visits to measure additional



physical data, and to collect water samples and tailings core samples for chemical and mineralogical characterization of the tailings.

Data accumulation at the two test sites included the following parameters:

	<u>Site A</u>	<u>Site B</u>
- atmospheric conditions	x	
- snow cover and ice thickness	x	x
- tailings temperature profiles	x	x
- pore pressures within the tailings	x	
- tailing moisture content and density	x	x
- seepage flows and analyses	x	
- surface run-off analyses	x	
- incoming tailings water analyses (whole facility)		
- radon emanation	x	x
- gamma radiation	x	x

Data accumulation from the site was reasonably effective, although some difficulties were experienced with pore pressure transducers, the data logging equipment and a nuclear density probe used for measuring moisture content and density. Data were collected from October 1984 to March 1985.

Physical data recorded for the tailings has enabled a reasonable explanation of the observed tailings behaviour to be undertaken. The tailings at Site A were deposited over a short period of time in the summer of 1984 to a depth of 2 metres. Initial excess pore pressures were observed with subsequent drainage and the development of suction pressures throughout the tailings by January 1985. Recorded densities in the tailings were relatively low and in the order of 0.5 t/m^3 . Frost penetration over the winter was in the order of 300 mm.



Knight and Piessold Ltd.

CONSULTING ENGINEERS

In general, physical parameters measured for the tailings indicate that behaviour is significantly influenced by the gypsum and other precipitates, constituting up to 30 percent of the total solids. Fairly low densities have been recorded to date, in the order of 0.5 t/m^3 at Site A and 0.65 t/m^3 at Site B. However, these values are specific to the monitoring sites and do not reflect average annual values for the whole facility. They may also be influenced in part by abnormal operation of the facility after start-up, when only part of the full area was available for tailings deposition.

Saturated permeability values for the tailings were measured in the order of $1 \times 10^{-7} \text{ m/s}$, with a reduction of approximately one order of magnitude after consolidation under the anticipated full depth of tailings. Of major significance is the reduction in permeability that occurs once suction pressures are developed and the material becomes unsaturated. A reduction of up to four orders of magnitude ($k < 1 \times 10^{-11} \text{ m/s}$) was measured for a suction pressure of 1 metre of water. This characteristic has a significant impact on reducing the movement of water through the tailings once unsaturated conditions have been established.

Measurements of gamma radiation and radon exhalation rates agreed with previous predictions. Given the high moisture content of the tailings, both gamma fields and radon emissions are low. Measured values of gamma radiation ranged from 1.4 to 2.8 mrad/hr and radon emanation rates were found to agree well with rates predicted in the EIS, with a value of $2.1 \text{ Bq/m}^2 \cdot \text{sec}$ for a wet tailings beach. Neither is of major concern in the long term as the area is to be capped with an engineered cover.

This study has produced a good understanding of the chemical and radiological properties of the Key Lake tailings solids and liquids. As a result of the leaching study and the geochemical modelling, reasonable predictions of the long term seepage quality from the tailings deposit have been made.



Association
of Consulting
Engineers
of Canada

Association
des Ingénieurs-
Conseils
du Canada

In general, these uranium tailings are mineralogically very different from uranium tailings encountered elsewhere in Canada in that they are non-acid generating with the major constituents and radionuclides being extremely stable.

Detailed seepage modelling was carried using a transient finite element seepage program developed by the University of Saskatchewan. This modelling indicated that the tailings material becomes the major barrier to significant moisture movement once partial saturation occurs and suction pressures are developed, due to the very significant resulting decrease in permeability. Best estimates of potential total seepage from the base of tailings are approximately $50 \text{ m}^3/\text{yr}$ at the end of operations and less than $10 \text{ m}^3/\text{yr}$ in the long term (300 to 500 years) after decommissioning. These values are insignificant and considerably lower than the detection limits of the underdrainage and monitoring systems. For comparison, a conventional wet disposal system of equivalent area relying on a containment seal with a permeability of $1 \times 10^{-8} \text{ m/s}$ could produce seepage in excess of $10,000 \text{ m}^3/\text{yr}$ at the end of operations.

Measurements of seepage collected at Site "A", the extensively instrumented site, showed that the pH ranged from 7.1 to 7.4, lower than the incoming and surface runoff pH of over 11. The principal constituents of the seepage are calcium and sulphate at the saturation level of gypsum. Concentrations of all significant metals in the seepage are low at less than 1 mg/L. The only radionuclide at significant levels in the seepage was Ra^{226} at 12 and 45 Bq/L. This compares with Ra^{226} values for the whole facility measured at 2.6 to 25 Bq/L, mean 7.1 Bq/L.

Porewater was extracted from cores taken from both test sites. The pH of the porewater ranged from 9.3 to 11.1. Arsenic levels ranged from 0.3 to 2.2 mg/L and Ra^{226} ranged from 10 to 55 Bq/L. Uranium levels were very low at less than 0.005 mg/L. Simple washing tests were done on two dewatered



Knight and Piccolli Ltd.

CONSULTING ENGINEERS

cores. Wash ratios of 4:1 (water/solids) in three stages were selected to approximate the maximum possible infiltration of water over 1000 years. Under these test conditions, the pH of the wash water was shown to decrease from alkaline to neutral and the concentrations of Ra²²⁶ and arsenic increase with increasing wash ratio.

The environmental effects of the potential seepage in terms of water quality degradation or radioactive dose to man will depend upon the seepage flow path, dilution, natural retardation processes and the location of potential receptors. Seepage volume is predicted to be low during operation and in the long term after facility decommissioning. Concentrations of contaminants in the seepage will depend on interactions with barrier materials.

A Phase II monitoring study has been proposed to continue field monitoring and data accumulation over a full year of operation, and to improve the understanding of the physical behaviour of the tailings. A testing program and contaminant transport model is also proposed to use data generated from the study in assessing the long term implications of any potential seepage.



Association
of Consulting
Engineers
of Canada

Association
des Ingénieurs-
Conseils
du Canada

SECTION 2.0 - INTRODUCTION

2.1 OBJECTIVES AND TERMS OF REFERENCE

The basic objective of the monitoring study was to obtain information on the detailed behaviour of the mineralogically-complex uranium tailings at the Key Lake Mining Corporation (KLMC) operations, to support long-term behaviour predictions of these tailings deposited by the sub-aerial method.

The Key Lake mining and milling operation, located in central north Saskatchewan approximately 43 kilometers east of Cree Lake, started up in October 1983. A tailings storage facility was designed and constructed to achieve full consolidation and the elimination of seepage from the tailings while the mine is in operation. This facility is also the first to receive wastes from the recently discovered high grade uranium ore bodies in Northern Saskatchewan, which represent the most significant sources of uranium in Canada.

The tailings storage facility incorporates instrumentation to monitor the overall performance of the facility. This instrumentation is essentially external to the tailings itself and monitors the facility on a macro-scale. However, the opportunity existed to determine in detail the nature and behaviour of the actual tailings during deposition, and to generate information required for long-term predictions. This gave rise to this monitoring study under the auspices of the National Uranium Tailings Program. The results of Phase I of the study are presented in this report.

The original statement of work for Phase I of the study is included in Appendix AI. Authorization to proceed was obtained on July 3rd, 1984. In



January 1985 the contract was amended to include some additional monitoring, chemical analyses and seepage modelling. The terms of reference for the additional work are included in Appendix AII.

2.2 DESIGN FEATURES OF THE TAILINGS STORAGE FACILITY

The principal design objectives of the tailings storage facility are to achieve a system whereby seepage discharge to the environment will be reduced to negligible proportions during operation, and to ensure that at decommissioning, the tailings will be fully drained and consolidated such that immediate construction of a surface seal can be carried out to control long-term seepage.

The principal design features of the tailings facility are as follows:

- (i) The base of the entire facility is covered by a sloping underseal constructed by bentonite modification of the in-situ till material. Overlying the underseal is a sand filter blanket and perforated drainage pipe system to intercept and remove all vertical seepage from the tailings.
- (ii) The design requires the tailings slurry to be deposited in thin layers over the filter blanket in rotational sequence, to produce a tailings beach sloping towards the main embankment. This 'sub-aerial' deposition, meaning beneath air as opposed to beneath water, enhances liquid solid separation and produces a laminated tailings deposit with a low coefficient of vertical permeability. By maintaining the tailings surface free of ponded surface water, evaporation from the beach is maximized. Evaporation from the surface develops negative pore pressures within the tailings which produce further consolidation of the material, leaving it in a structurally stable condition with minimal potential for on-going seepage.



- (iii) The main embankment incorporates a pervious upstream zone to continuously decant precipitation and supernatant water and to prevent any significant ponding of water on the tailings beach. A pump station outside the main embankment recycles the supernatant water and underdrainage outflows to water reservoirs at the mill site, where the water is treated prior to release to the environment.

In addition to addressing design objectives with regard to seepage from the tailings, by maximizing liquid solid separation and air-drying of the tailings the design also serves to consolidate the tailings to densities significantly in excess of those that could be achieved by conventional sub-aqueous deposition, with a resulting improved storage utilization.

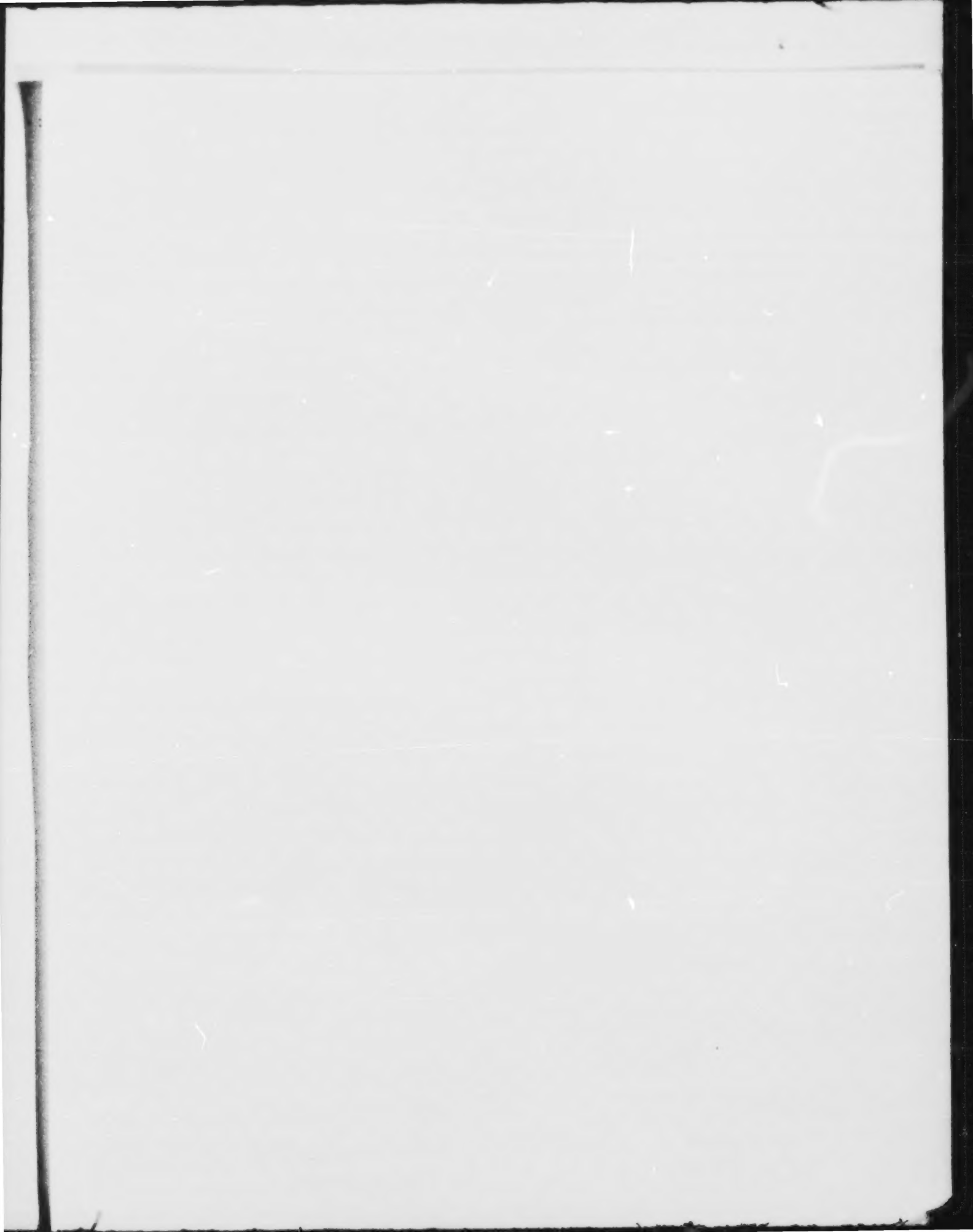
The tailings storage facility at the Key Lake site is located approximately 1.5 km west of the mill site on a broad till ridge. The general layout of facility and local topography is shown on Figure 2.1 and a typical cross-section through the facility is shown on Figure 2.2.

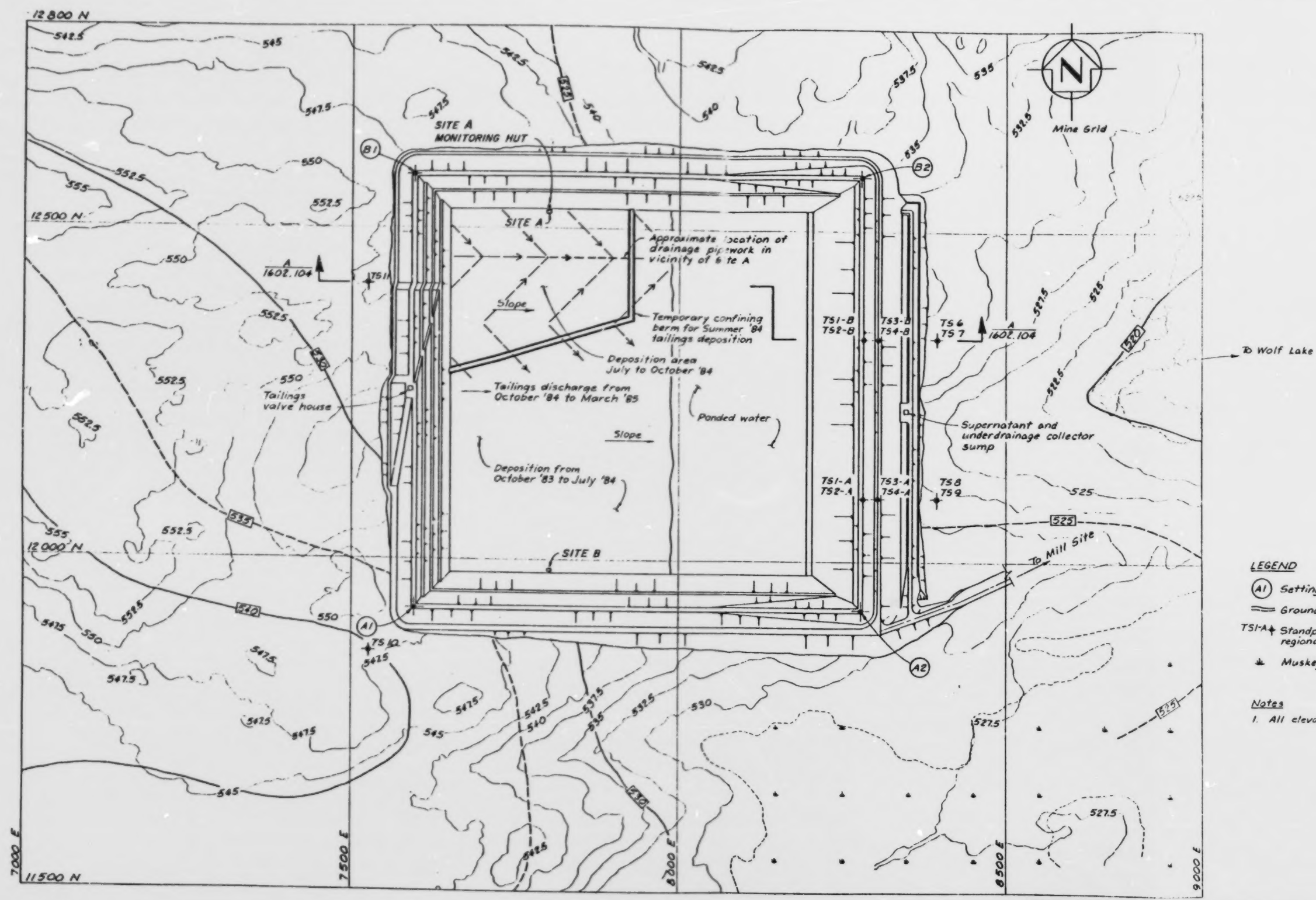
2.3 MONITORING INSTALLATIONS AND STUDY OUTLINE

Monitoring installations for the study are located at two sites, Site A and Site B, at the locations shown on Figures 2.1 and 2.2. Site A contains an impervious liner and sump pump beneath the tailings and is instrumented for continuous measurement and recording of atmospheric and tailings physical data using a data logger. Site B was used in conjunction with Site A for periodic visual observations and measurement of various tailing parameters. Water sampling of various liquid streams was also carried out periodically. Parameters measured during the study included:

- atmospheric conditions
- snow cover and ice thickness
- tailings temperature profiles







LEGEND

(A1) Setting out points

— Groundwater table contours

TS1-A Standpipe piezometers for regional groundwater monitoring.

✱ Muskeg

Notes

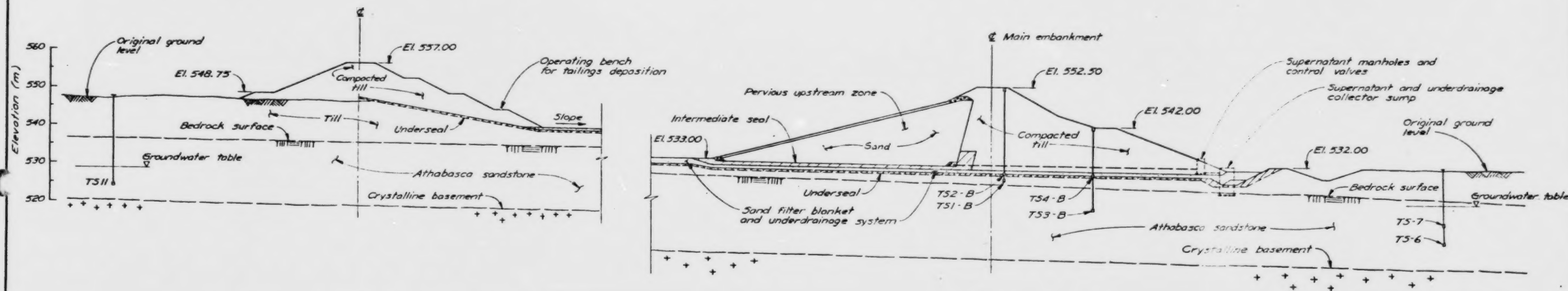
1. All elevations are in metres

Scale 100 50 0 100 200 300 m

KNIGHT AND PIESOLD LIMITED CONSULTING ENGINEERS - VANCOUVER, B.C.		SUPPLY AND SERVICES CANADA MONITORING OF LAYERED URANIUM TAILINGS PHASE I	
DESIGNED		TAILINGS STORAGE FACILITY GENERAL ARRANGEMENT	
DRAWN	<i>W. J. P.</i>		
CHECKED	<i>J. A. P.</i>		
APPROVED	<i>J. A. P.</i>		
DATE APRIL 4, 1985		SCALE AS SHOWN	DRG. NO. 1602.103

REV.	DATE	DESCRIPTION	APPROVED	REV.	DATE	DESCRIPTION	APPROVED

FIGURE 2.1



SECTION ^A 1602.103

NOTE

All elevations are in metres.

Scale 10 5 0 10 20 30 40 50 m

REV. NO.	DESCRIPTION	REV.	DATE	DESCRIPTION	APPROVED	REV.	DATE	DESCRIPTION	APPROVED
REFERENCE DRAWINGS		REVISIONS		REVISIONS		REVISIONS		REVISIONS	

KNIGHT AND PIESOLD LIMITED CONSULTING ENGINEERS - VANCOUVER, B.C.		SUPPLY AND SERVICES CANADA MONITORING OF LAYERED URANIUM TAILINGS PHASE I	
	DESIGNED	TAILINGS STORAGE FACILITY TYPICAL CROSS-SECTION	
	DRAWN WAL		
	CHECKED J. P. Martin		
DATE APRIL 4, 1985		SCALE AS SHOWN	REV.
DRG. NO. 1602.104		REV.	

FIGURE 2.2

Knight and Piesold Ltd.

CONSULTING ENGINEERS

- pore pressures within the tailings
- tailings moisture content and density
- seepage flows and analyses
- surface run-off analyses
- incoming tailings water analyses
- radon emanation from the tailings surface
- gamma radiation

Monitoring installations were generally commissioned in September and October 1984, and specific details of data and sample accumulation methods are given in Section 3.0.

In November 1984, core samples of tailings were extracted from both Sites A and B for laboratory test work. The test work consisted of determination of geotechnical parameters and chemical and mineralogical characterization of the tailings. The geotechnical test work was carried out by the Engineering Department of the University of Saskatchewan and the parameters subsequently used in finite element seepage analyses, carried out in conjunction with the University. Chemical analyses and test work were carried out by Saskatchewan Research Council and included determination of the chemical and mineralogical properties of the tailings solids and chemical properties of the tailings liquids.

Geochemical characterization of the tailings has been carried out by SENES Consultants Limited who prepared Sections 7, 8 and 9 of this report. Work on physical characterization of the tailings and long-term seepage predictions has been carried out by Knight and Piesold Ltd.

A schematic of the study outline is shown on Figure 2.3.



Association
of Consulting
Engineers
of Canada

Association
des Ingénieurs-
Conseils
du Canada

MONITORING OF LAYERED URANIUM TAILINGS - PHASE I

STUDY OUTLINE

FIELD MONITORING

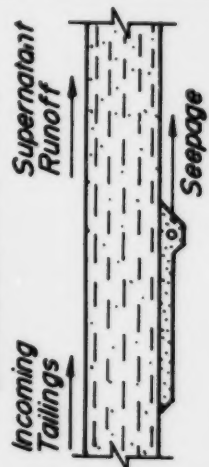
SITE A

Physical observations
and measurements

Microscout data
logger

Core samples

Water samples



SITE B

Physical observations
and measurements

Core samples

TESTWORK AND DATA PROCESSING

Tailings physical data

Atmospheric data

Geotechnical parameters

Water sample and pore
water analysis

Chemical and mineralogical
properties

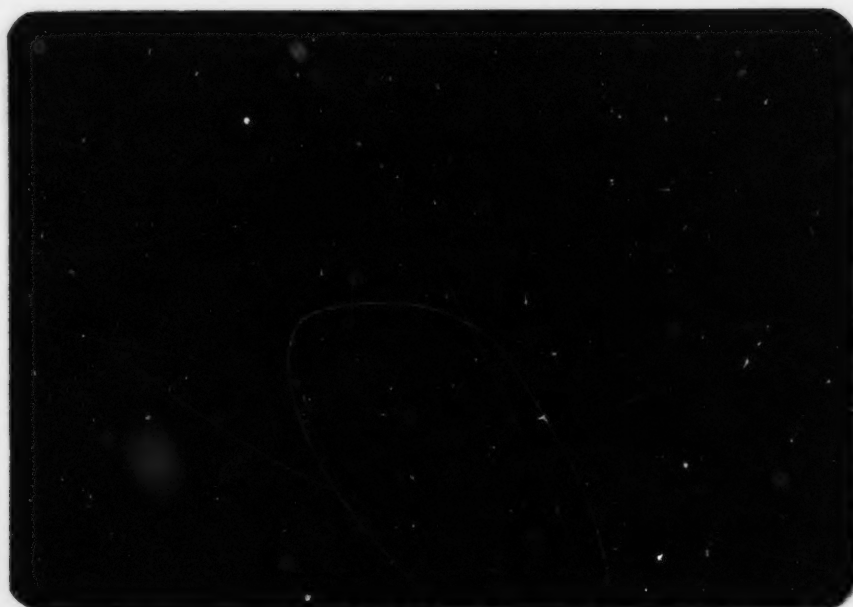
MODELLING

PHYSICAL CHARACTERIZATION
Consolidation and Seepage
modelling

GEOCHEMICAL
CHARACTERIZATION



Photograph No. 1 Aerial view of tailings facility looking north. (March, 1985)



Photograph No. 2 Monitoring hut at Site A. Stevens screen, pyranometer and rain gauge at left. Site A with standpipes and moisture density access pipes at right.

2.4 BRIEF HISTORY OF DEPOSITION

Tailings deposition into the tailings storage facility commenced in October 1983 with the first winter layer being discharged on the south side of the facility as shown on Figure 2.1. Deposition continued over this area until July 1984, and resulted in a build-up of tailings of approximately 1.2 metres at Site B.

Initial operation of the tailings facility has been somewhat atypical due to the temporary storage of excess water in the facility since mine start-up. This water was not related to tailings deposition but was stored as a contingency measure due to remedial work required on water storage reservoirs and treatment facilities elsewhere in the plant. The pond level reached a maximum in July 1984 at El. 538.00 which accounted for storage of approximately 500,000 m³.

Tailings deposition was switched from the south to the north side of the facility in July 1984 as shown on Figure 2.1. Prior to switching, a small confining berm was constructed in the north west quadrant of the facility to confine the summer discharge above the ponded water. The area behind this berm was essentially full by October 1984 and tailings discharge has continued down the centre of the facility from that time, resulting in the build-up of a large fan of tailings over the south side of the facility. This is also shown on Photograph No. 1, an aerial view of the tailings facility looking north, taken in March, 1985.

Deposition on the north side resulted in the rapid build-up at Site A of approximately 2 metres of tailings between July 1 and mid October 1984, with no discharge over this area for the remainder of this study period. The main build-up of tailings at Site A took place prior to final commissioning of the instrumentation at that site.



Knight and Piesold Ltd.

CONSULTING ENGINEERS

An Ion Exchange treatment plant for the removal of radium from the excess water was commissioned in October 1984, and all excess water stored in the tailings facility was recycled and treated by the end of January 1985.



Association
of Consulting
Engineers
of Canada

Association
des Ingénieurs-
Conseils
du Canada

SECTION 3.0 - ACCUMULATION METHODS

3.1 GENERAL

This Section describes the methods by which the data and samples used in the study were collected, and discusses any interpretations or corrections applied to the field data prior to presentation.

Because of the remote location and the desire to minimize the demands on mine operating personnel it was essential to choose instrumentation capable of operating for periods of several months without supervision.

Failures and shortcomings of several instruments highlighted the severe operating environment and the necessity for all equipment and sensors to be comprehensively checked before being shipped to site and installed. Insufficient lead time and delays in equipment delivery contributed to later difficulties. However most equipment shortcomings were related to atmospheric measurements made for comparison with data recording equipment at the KLMC climatological station, and required for evaluation of evaporation. The timing of this phase of the study therefore reduced their significance. Actual field data and results of analyses and tests carried out on field samples are reported in subsequent sections under the relevant topic.

3.2 CONTINUOUS MONITORING EQUIPMENT

A 16 channel "Microscout" data logger, equipped with 12K of RAM memory and supplied by Applied Instrumentation Ltd., was employed to continuously monitor sensors installed both in the tailings and on the embankment adjacent to the test site, at Site A. The data logger is powered by two



Knight and Piccolli Ltd.

CONSULTING ENGINEERS

rechargeable 9v batteries and is designed for minimum power consumption so as to prolong the time between visits.

The following sensors were installed:

(i) Atmospheric Conditions:

Temperature	-	2 Units	(including one in the relative humidity sensor).
Relative Humidity	-	1 Unit	
Insolation	-	1 Unit	
Precipitation	-	1 Unit	
Wind Speed	-	1 Unit	

(ii) Within Tailings:

Temperature	-	3 Units	
Pore Pressure	-	4 Units	(6 channels provided)
Seepage Flow	-	1 Unit	(attached to pump discharge pipework in the monitoring hut).

A schematic of the data logger showing the channel to which each sensor was connected is included as Figure 3.1.

Throughout the monitoring period the data logger was programmed to carry out a sensor scan at three hourly intervals. This allowed for the accumulation of up to 41 days of data. Normally data was extracted from the unit at intervals not exceeding one month.

Data was removed from the data logger on a cassette tape in a hexadecimal format. Software from the "Microscout" supplier allowed this data to be

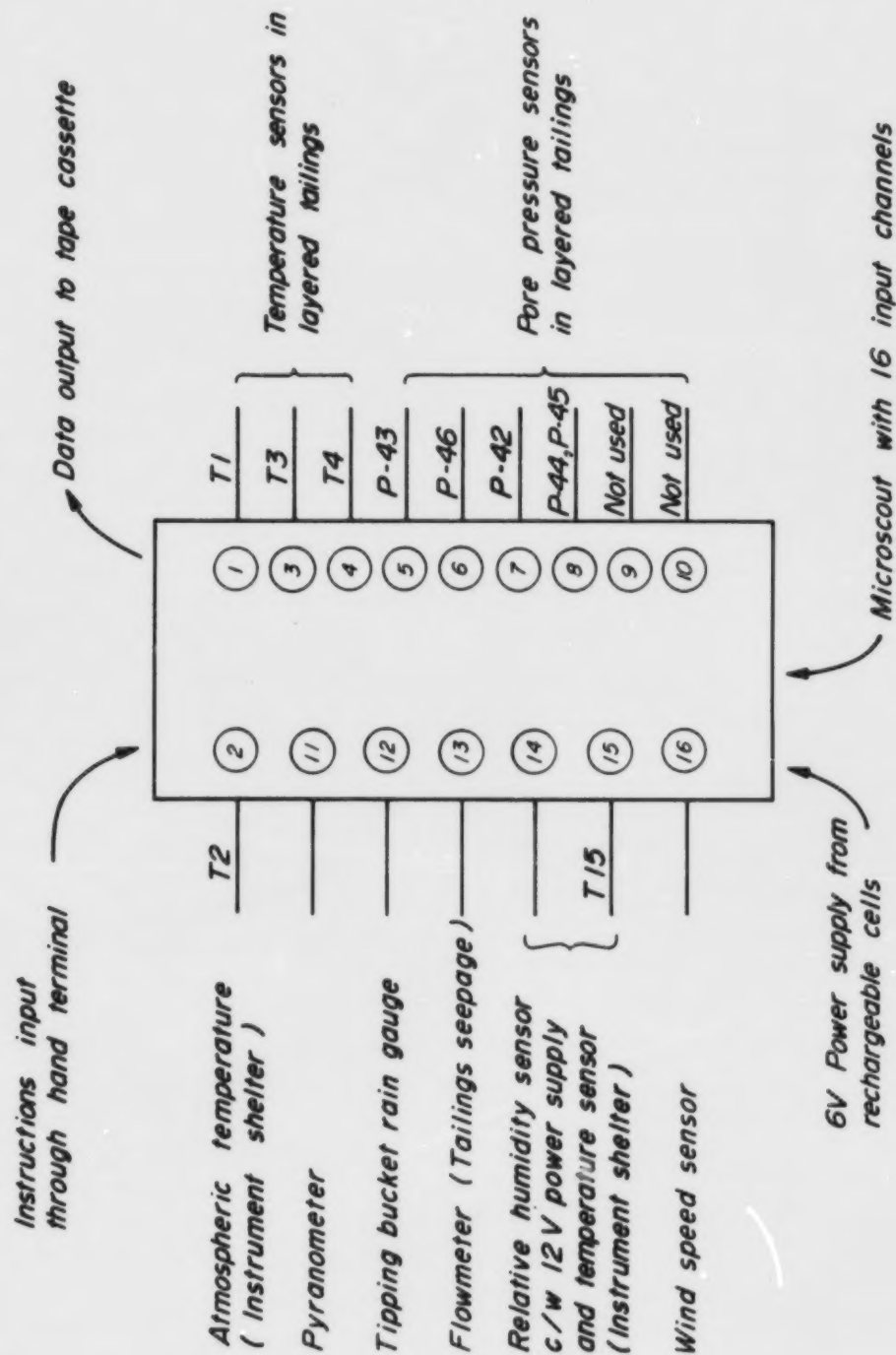


Association
of Consulting
Engineers
of Canada

Association
des Ingénieurs-
Consultants
du Canada

MONITORING OF LAYERED URANIUM TAILINGS - PHASE I

INSTRUMENTATION CONNECTED TO "MICRO-SCOUT"



read to a computer disc in integer format. Software developed as part of this work allowed this data to be presented in report form in engineering units, as well as data correction, the preparation of monthly summaries and the plotting of selected data.

The data logger was brought into service on September 17, 1984 and monitoring was terminated on March 9, 1985. During this period two service breaks totalling 4 weeks occurred, one as a result of an operator programming error, and one from an electrical failure within the data logger which required removal of the unit from the site for repair by the supplier. Data losses also occurred from some channels due to the severing of sensor cables by rodents. Where possible the sensor performance was thereafter reviewed at each site visit to ensure the integrity of the unit. Cables were also threaded through plastic conduit to provide protection.

Generally the "Microscout" proved relatively simple to use and reliable in recording and yielding data. However, because of the time constraints on equipment selection and installation and the lack of opportunity to carry out a detailed sensor verification programme prior to shipment, the on-site performance of the system was not wholly satisfactory. However, rectification of outstanding problems can be carried out with removal of the unit from site to upgrade the software and recalibrate relevant sensor channels.

Details of individual sensors and comments on their general performance are discussed in the following sub-sections. The data recorded by the sensors is presented in Sections 4 and 5.

3.2.1 Temperature Sensors - Site A

Temperature sensors at Site A are an integrated circuit type, Model LM 335 Z by National Semiconductor, with a claimed accuracy of



$\pm 2^{\circ}\text{C}$. This type was selected for its linear output which facilitates input into the data logger.

Three temperature sensors were installed in the tailings at Site A as shown on Figures 3.2 and 3.3. The elevations are summarized below:

<u>Sensor Identification</u> <u>Number</u>	<u>Elevation</u> (m)	<u>Height Above</u> <u>Filter Blanket</u> (mm)
T1	541.4	2000 (surface)
T3	540.4	1000
T4	539.5	100

A fourth sensor, T2 was installed in a Stevens screen and used to monitor atmospheric temperature.

A sensor verification programme using ice-water mixtures and two laboratory thermometers indicated that the temperature sensors were reading 1.5°C high. All reported temperature data has been corrected by -1.5°C . In addition, the "signal conditioner" for the temperature channels within the data logger was set with a low temperature cut-off at approximately -25°C and consequently the values for low temperatures have a minimum reported value of -27°C . Both these problems can easily be rectified by minor changes in the data logger firmware.

3.2.2 Relative Humidity Sensor

The relative humidity probe is a thin film capacitor type combined with an integrated circuit temperature detector, as described in Section 3.2.1 and is powered by a 12 volt battery external to the data



logger. The sensor was installed in a Stevens screen together with the independent atmospheric temperature sensor T2.

Initial problems with the design of this unit resulted in an unacceptable error in the associated temperature data. Additional design problems resulted in the failure of the probe due to electrical overload. It was suspected that the 12 volt source also affected data collected from other sensors. Owing to these on-going concerns and the limited relevance of humidity readings during winter operation, these combined sensors were disconnected in December 1984.

3.2.3 Insolation

A Middleton Instruments SP237-126 pyranometer was installed to allow an estimate to be made of the daily sunshine hours during the time when evaporation from the tailings surface would be significant.

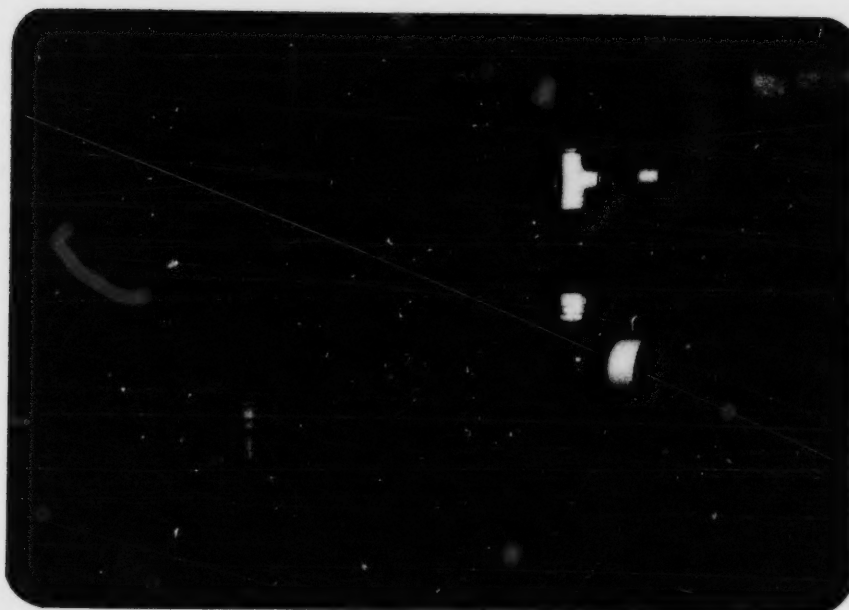
3.2.4 Precipitation

An M.I.C. Model 2500 tipping-bucket rain gauge was installed to monitor precipitation and was capable of reporting rainfall in 0.25 mm increments. Snowmelt was not reported due to the lack of wind shielding and the inability of the unit heaters to adequately melt accumulated snow. While data on snowfall was not relevant to this work, a check on precipitation is available by reference to the information collected at the KLMC climatological station.

3.2.5 Wind Speed

A Met One Model 013 wind speed sensor was installed in November 1984 at the location shown on Figure 3.3. The unit makes a five second pulse count at each data logger scan, and records an average





Photograph No. 3 Seepage flow meter and water sampling pipework inside monitoring hut.



Photograph No. 4 Gamma radiation instrument in use 1 metre above frozen tailings surface at Site A.

wind speed from the count. Pulses are not accumulated between sensor scans. The unit reports any wind speed of 1 mile/hour or less as 1.6 km/hour.

For reporting purposes wind speed was transformed into an equivalent 24 hour wind run in kilometres. Readings of 1.6 kmph were assumed to denote a zero wind speed for the time interval between data logger scans.

3.2.6 Seepage Flow

Seepage collected from the Site A underseal collection drain was pumped to discharge through a flow meter. The flow meter is a 3/4 inch dial type with totalizing counter and contactor, by Liquid Metronics Inc. The flow meter reports 10 litre increments of flow to the data logger. A check between flow meter totalizer readings and accumulated microscout data showed a satisfactory correlation.

3.2.7 Pore Pressure Transducers

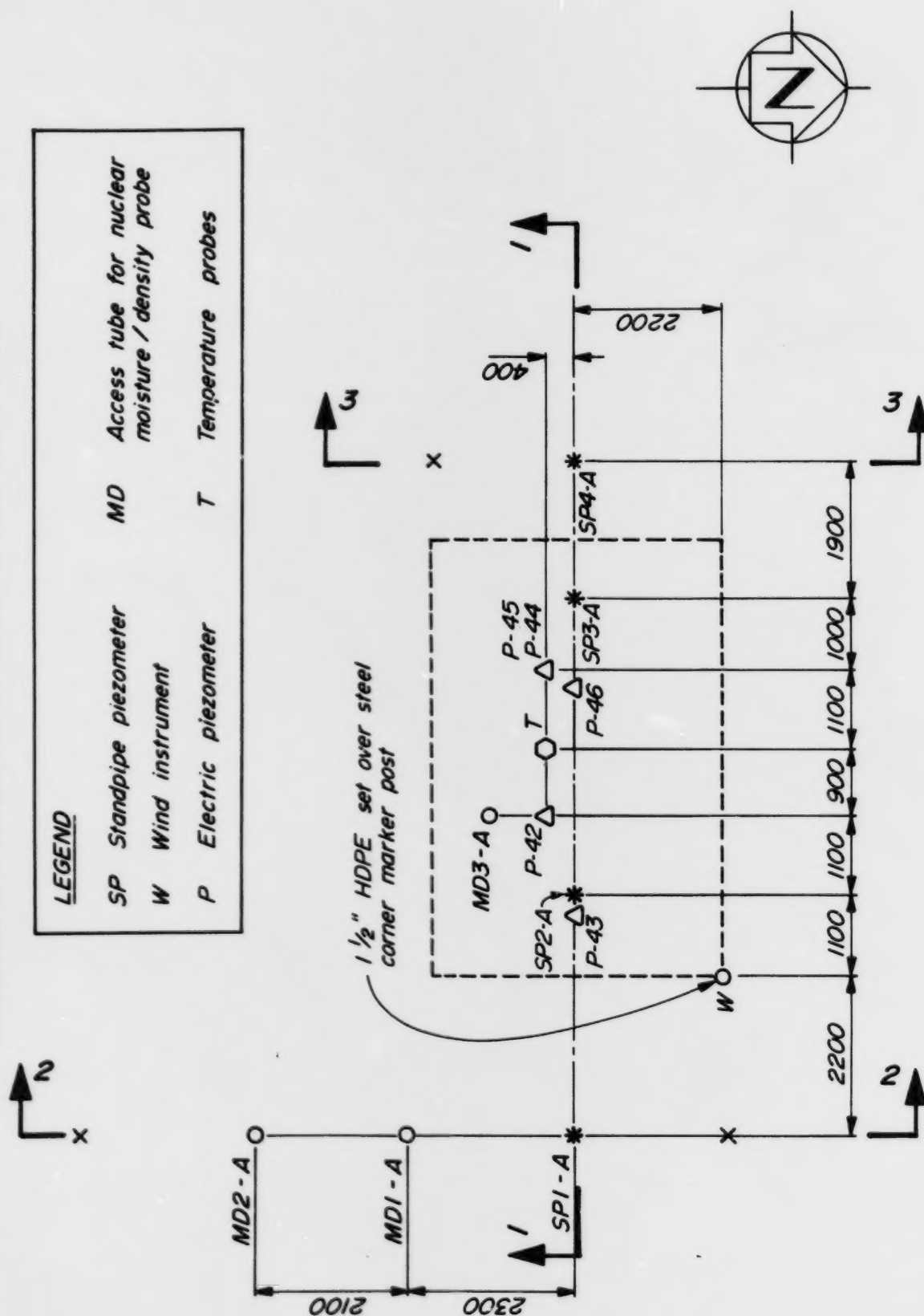
The pore pressure transducers used are of the integrated silicon strain gauge bridge type, and were specially made for this application which requires measurement of negative pore pressure. While other types of pore pressure transducers were available for continuous monitoring (e.g. pneumatic, vibrating wire) they could not be justified for this work due to the complexity of their control and operating systems, expense and long delivery time.

Each piezometer is fitted with two hydraulic flushing leads connected to the space within the high air entry Coors filter stone. Pressure operated check valves are incorporated on the flushing leads within the piezometer body. The check valve opening pressures are 21.1 m



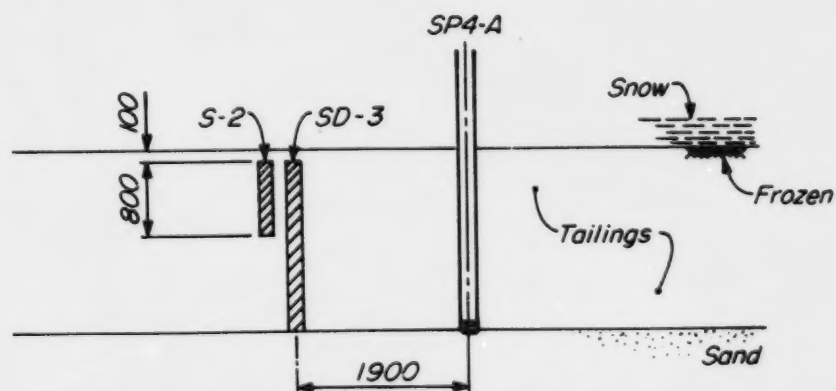
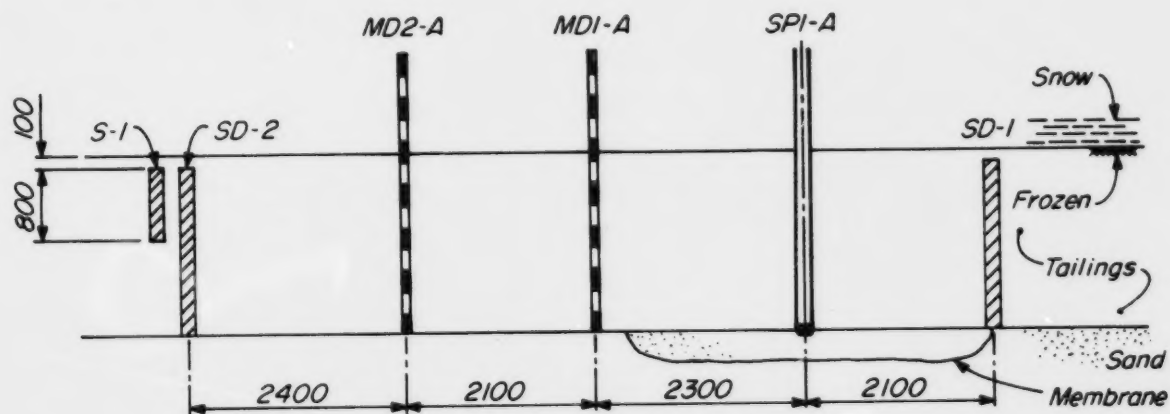
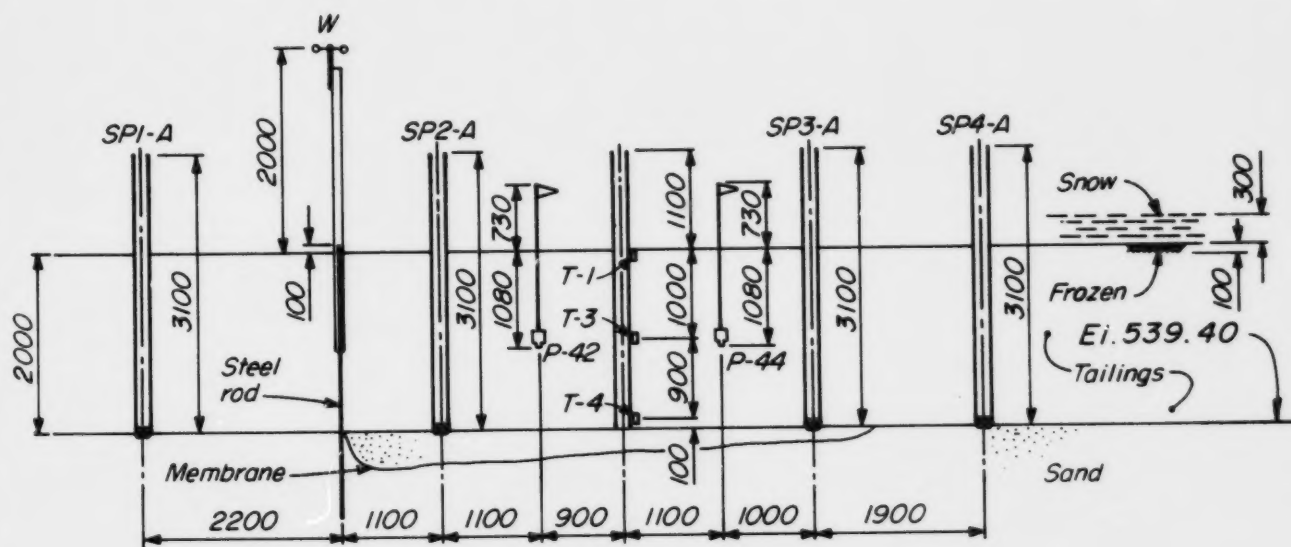
MONITORING OF LAYERED URANIUM TAILINGS - PHASE I **SCHEMATIC OF MONITORING INSTALLATIONS - SITE A**

LEGEND			
SP	Standpipe piezometer	MD	Access tube for nuclear moisture / density probe
W	Wind instrument	T	Temperature probes
P	Electric piezometer		



MONITORING OF LAYERED URANIUM TAILINGS - PHASE I

SCHEMATIC OF MONITORING INSTALLATIONS - SITE A



water head on the incoming lead, and 1.4 m water head on the return lead. Specifications of the pore pressure transducers are:

Pressure range:	-8.0* to 7.2 m water (-11.4* to + 10.3 psia)
Maximum pressure:	14.5 m water (20.6 psia) at the piezo- meter
Accuracy:	+0.5% over temperature range - 1.1°C to 54.4°C.
Supplier:	R.S. Technical Instruments Ltd.

*limited by Coors stone.

Five pore pressure transducers were installed in the tailings at test Site A, Units P43 and P46 during construction of the test site, Units P42 and P44 when freezing allowed access to the site, and Unit P45 as a replacement for P44.

Installation dates and elevations for the sensors are given below. The locations of the sensors are shown on Figures 3.2 and 3.3.

<u>Pressure Sensor</u>	<u>Tip Elevation at Installation</u> (m)	<u>Height Above Filter Blanket</u> (mm)	<u>Date of Installation</u>
P42	540.21	810	November 21, 1984
P43	539.95	550	October 3, 1984
P44	540.21	810	November 21, 1984*
P45	540.31	910	January 9, 1985
P46	539.75	350	October 3, 1984
P47	Not Installed		



*Removed January 9 and replaced by Unit #45.

It became apparent soon after their installation that Units P42 and P44 were not performing satisfactorily, with zero errors far greater than those verified prior to delivery to site. Unit P47 was not installed and was returned to Vancouver to investigate the problems with the sensors. Tests carried out on Unit P44 after its removal from the tailings confirmed the major shift in zero error from that cited by the supplier.

The excessive number of corrections and drift in the sensor characteristics means that the results can only be used as an indication of pore pressure changes and not as absolute pressure values. Also, because Units P42, P44 and P45 could not be flushed owing to the freezing conditions, negative pore pressure readings may be subject to some inaccuracy. For future work the pressure sensors will be replaced under warranty by the supplier. Future units will not be equipped with flushing leads and one of the six sensors will be used as an atmospheric pressure reference only.

3.3 MOISTURE DENSITY GAUGE

To determine changes in the in-situ density and moisture content of the tailings at both Site A and Site B a portable Model 501 moisture/density gauge manufactured by Campbell Pacific Nuclear Corporation was used. The gauge consists of an electronic counter and a probe containing a Cesium 137 radio-active source, providing gamma radiation, and an Americium 241/Beryllium source, providing fast neutron radiation. The probe is lowered down a series of 1.5 inch diameter schedule 40 PVC access pipes embedded in the tailings. Three pipes designated MD1-A to MD3-A were installed at Site A, and three at Site B designated MD1-B to MD3-B. The locations of the probe pipes are shown on Figures 3.3 and 3.4.



MONITORING OF LAYERED URANIUM TAILINGS - PHASE I

SCHEMATIC OF MONITORING INSTALLATIONS - SITE B

MD - Moisture Density Probe
T - Temperature Probe

Surface-El. 538.9 Nov 1984
El. 539.5 March 9, 1985

Tailings

2.5

Till

6

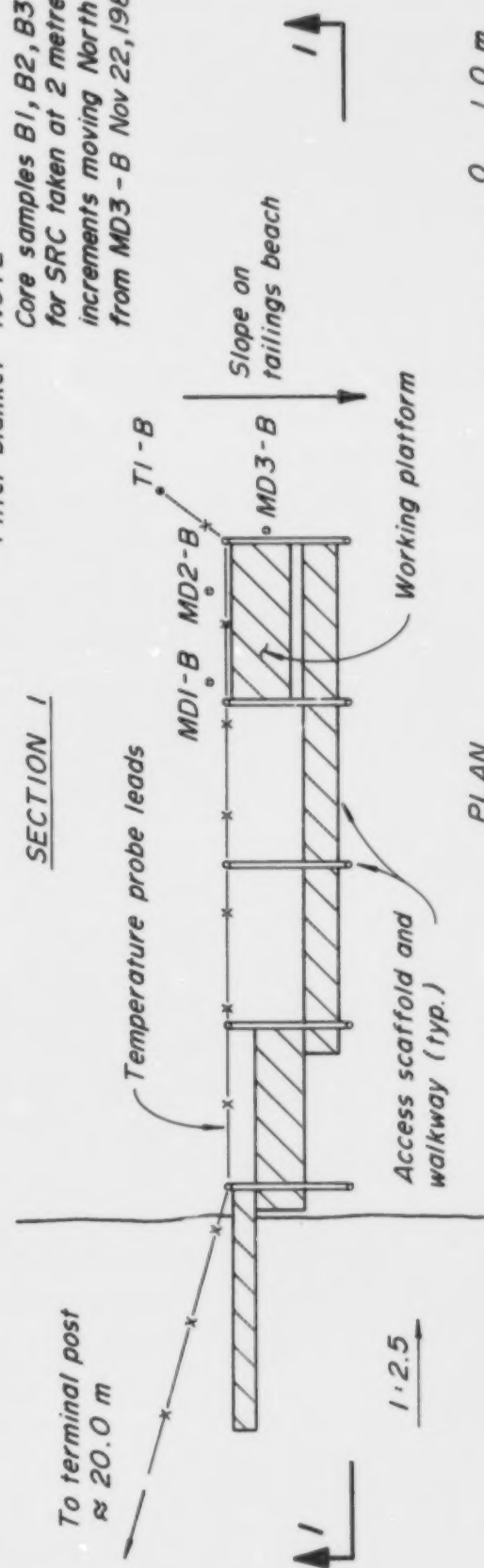
Till / bentonite underseal

Filter blanket

NOTE:

Core samples B1, B2, B3
for SRC taken at 2 metre
increments moving North
from MD3-B Nov 22, 1984

SECTION 1



PLAN

Approx. scale 0 1.0 m

Knight and Pirosold Ltd.

CONSULTING ENGINEERS

Density readings are provided by measuring gamma back scatter from the tailings, with a correction required to account for the radio-active content of this source. Moisture readings are provided by measuring the slow (thermal) neutron return flux resulting when fast neutrons from the source are slowed by collision with hydrogen atoms in the surrounding media.

The moisture density gauge requires calibration for both density and moisture because of the high background radiation and hydroxyl ion concentration in these tailings. Calibration curves were developed by plotting readings derived from the gauge data against field measurements. Refinement of these curves will continue as thawing ice conditions permit additional sampling of in-situ tailings for correlation with the instrument readings. As reported in Section 5.5 and 5.6 the determination of moisture content in field samples is influenced by the complex tailings chemistry and correlations to date have not been properly established.

Prior to using the gauge in the field a standard count is made on both the density and moisture channels to verify satisfactory performance of the equipment.

At each location the access pipe was swabbed dry if necessary prior to inserting the probe. The probe was then lowered down the pipe and a series of readings made at 200 to 300 mm increments to full depth on both the density and moisture channels. A second set of readings was then made using a dummy probe, which contained no radio-active source, to compensate for background radiation in the density readings.

The ratio of gauge reading to standard count was calculated for each observation point and the calibration curves used to calculate bulk density and moisture content.

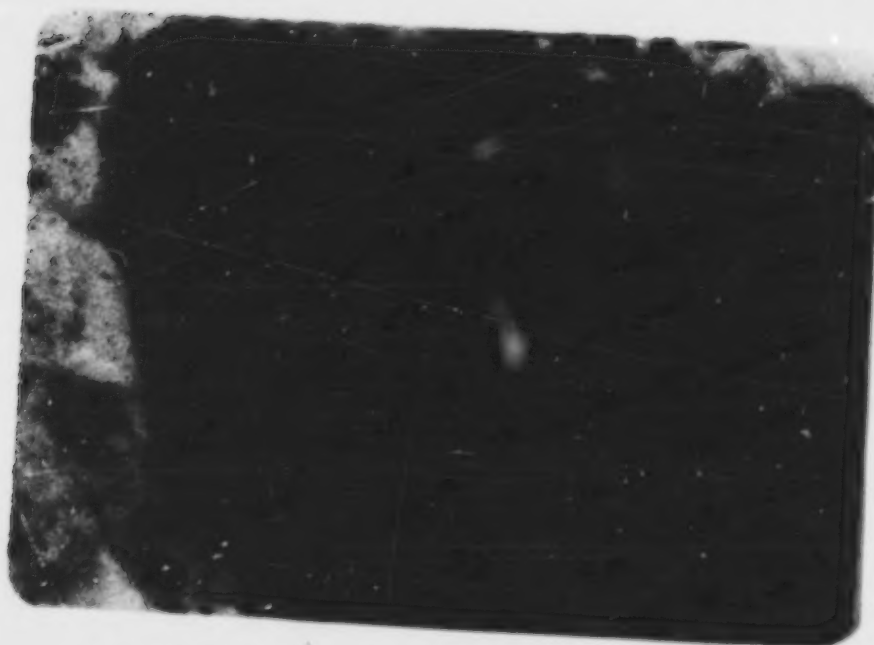


Association
of Consulting
Engineers
of Canada

Association
des Ingénieurs-
Conseils
du Canada



Photograph No. 5 Site A. Moisture density gauge with probe down access tube. Standpipe piezometer at left, soil temperature mast at right.



Photograph No. 6 Site A. Radon accumulator at left. Ice thickness approximately 350 mm with core sampler in place for sample extraction.

The continual interchanging of the dummy probe and the radioactive probe under conditions of widely varying temperature resulted in stripping of the connecting thread making the instrument unuseable. The unit was returned to the supplier for repair at the end of this phase of the work.

3.4 RADIATION MEASUREMENTS

Radiation monitoring at both sites consisted of measurements of gamma radiation trade work a survey meter, and of radon exhalation rates using both "Track Etch"^r technology and solid state integrating radon meters.

3.4.1 Gamma Radiation

Gamma radiation measurements were made using a Model GS-500A Survey Meter by G.E. Smith and Associates. The unit was calibrated by the manufacturer to an energy of 0.661 M.E.V.

Readings were taken with the instrument held at approximately 1 metre above the surface. Where deep snow cover or ice cover existed several observations were made at the "hip level" of the observer both with and without prior snow removal.

For background purposes several readings were made at locations remote from the tailings test sites and also in the monitoring hut.

3.4.2 Radon Exhalation

The equipment used to measure the radon exhalation rate from the surface of the tailings consisted of a 23 litre collection chamber outfitted with three alphaMETER-400 integrating radon metres. The chamber was inverted on the surface of the test sites for periods of



several hours and readings of elapsed time and sensor count were taken at regular intervals.

The specifications of the can are as follows:

Height	0.39 m
Diameter	0.29 m
Monitoring Surface Area	0.06 m^2
Volume	0.023 m^3 (23L)

The alphaMETER-400 is an extremely sensitive, solid state, self contained, battery operated integrating radon gas meter. The meter was developed by alphaNUCLEAR as an exploration tool to obtain sensitive measurements of near-surface radon gas abundance as an aid in locating deep uranium deposits.

The high sensitivity of the instrument allows radon gas concentrations to be measured in-situ after only short integrating periods. The measured information, of integrating time in hours and total alpha counts, is displayed on the built-in numeric display.

The instruments were calibrated by Saskatchewan Research Council in Saskatoon, and by SENES Consultants Ltd. in Toronto. Since the output of the alphaMETER-400 is in total counts of alpha activity it was necessary to place the units in atmospheres of known radon concentration to establish conversion factors for counts of alpha activity per hour to picoCuries per litre of radon gas. The mean calibration factor for the instruments used was 1.09 CPH/pCi/L.



3.4.3 Subsequent Radon Measurements

A series of additional radon measurements were made using "Track EtchTM" Type M detectors which were placed on the surface of the test site for periods ranging from several days to one month. The "Track EtchTM" technique involves the use of a dielectric detector which responds to alpha particle radiation damage tracks from radon and its daughters. These tracks are etched at the end of the exposure period and counted to give a measure of the integrated alpha dose to the detector.

3.5 VISUAL OBSERVATIONS

Visual observations were made at both sites during site visits to assist in interpretation and understanding of the recorded data and the performance of the tailings facility. Factors such as general weather conditions, snow and ice depths, tailings discharge points and the tailings surface condition were noted.

3.6 WATER SAMPLING

Water sampling of various liquid streams was carried out on a routine basis. For this programme three water samples were collected:

- | | | |
|-------|-------------------|--|
| (i) | Incoming Tailings | - Water filtered from fresh incoming tailings. |
| (ii) | Surface Runoff | - Runoff from the tailings beaches, collected at a point downstream of Site A. |
| (iii) | Seepage | - Water pumped from the filter blanket underlying Site A. |



Water samples were collected in clean plastic buckets which were immediately capped to avoid contamination. Samples were vacuum filtered through fast filter papers to remove suspended solids, colloids, oils and colour and finally through a 3 micron millipore filter. All laboratory glassware and equipment was thoroughly washed and rinsed using 1% HNO_3 , deionized water and filtrate. Samples were left unpreserved or preserved with HNO_3 , as required for subsequent analysis or preserved with H_2SO_4 for nitrate determinations. Samples were dispatched either to the Key Lake Mining Company analytical laboratory on site, or to the Saskatchewan Research Council (SRC) analytical laboratory in Saskatoon.

Due to the freezing weather conditions it was not possible to collect surface run-off from the facility at all the designated sampling times. No seepage was collected from the filter blanket under Site A after January 7th, which precluded the collection of a full series of seepage samples. A summary of sampling dates and samples collected is listed in Table 3.1.

Details of analyses carried out on the various water samples are given in Section 8.0.

3.7 CORE SAMPLING

Eight tailings core samples were extracted from the test sites in November 1984, for geotechnical, chemical and mineralogical testing.

For geotechnical test work, two undisturbed cores approximately 500 mm in length and 75 mm in diameter were extracted from site using Shelby tube thin-walled samplers. These cores were designated A1 and A2. These cores were sealed on site prior to shipment to the University of Saskatchewan (U of S). In addition six disturbed core samples were extracted, three from each site and designated A3, A7, A8, B1, B2, and B3 and extruded into labelled plastic bags for shipment to SRC.



TABLE 3.1

KEY LAKE PROJECT
MONITORING OF LAYERED URANIUM TAILINGS - PHASE I

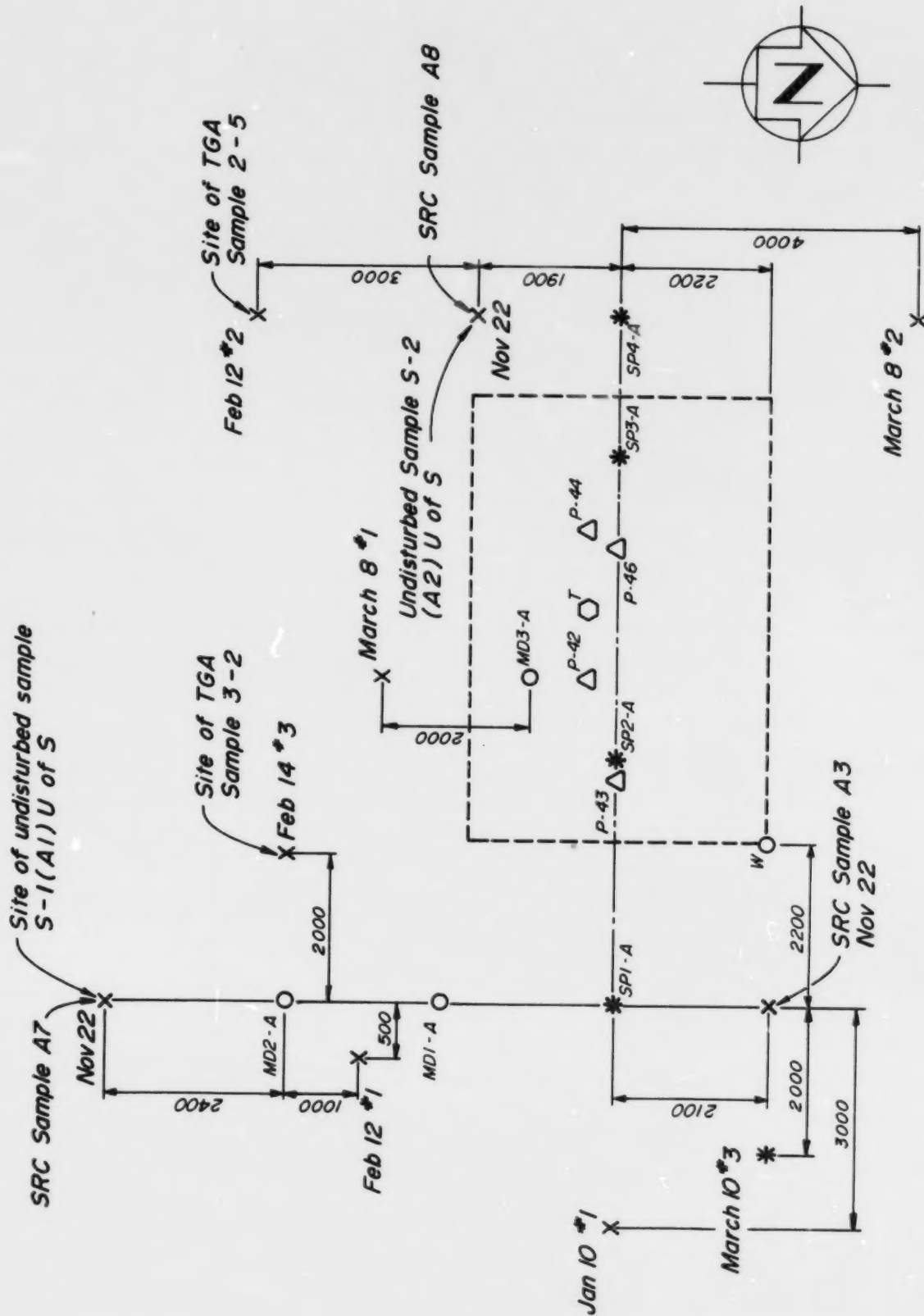
WATER SAMPLING PROGRAMME

<u>Date</u>	<u>Incoming Tailings</u>	<u>Surface Run-off</u>	<u>Seepage</u>
Sept. 16-17	Collected	Collected	Collected
Oct. 16	Collected	Collected	Collected
Nov. 21	Collected	Not Collected (1)	Not Collected (2)
Jan. 7	Collected (3)	Not Collected (1)	Collected
Feb. 11	Collected (3)	Not Collected (1)	Not Collected (4)
March 9	Collected (3)	Not Collected (1)	Not Collected (4)

NOTES:

- (1) Surface frozen - no suitable sampling site.
- (2) Seepage pump out of order.
- (3) Sample collected from tailings pumps in mill. All previous samples were taken from the discharge into the tailings facility which may have included recycled water.
- (4) No seepage water in pump sump.

MONITORING OF LAYERED URANIUM TAILINGS - PHASE I
SCHEMATIC OF SAMPLING LOCATIONS - SITE A



Photograph No. 7 Temperature monitor at Site B registering soil temperature 0.2 m above filter blanket on March 9.



Photograph No. 8 Access scaffolding at Site B with moisture density access tubes (white caps) and soil temperature mast.

From time to time, additional disturbed core samples were taken from Site A for moisture and density determination. To determine tailings moisture content and density, material was extruded from the sampler and dried overnight in air at a controlled oven temperature of 105°C. The locations of all core samples taken from Site A and Site B are shown on Figures 3.4 and 3.5.

3.8 THERMOGRAVIMETRIC ANALYSIS

Two samples designated 2-5 and 3-2 for thermogravimetric analysis were removed from Site A during February 1985, at the locations shown on Figure 3.5. These were subjected to thermogravimetric analysis by B.C. Research.

3.9 MISCELLANEOUS MEASUREMENTS

3.9.1 Temperature Sensors - Site B

Temperature sensors installed at Site B are thermistor probes Model K8430 -10 Series YSI Model 400, read by a portable LED display unit Model 8523-00, all by Cole Palmer Instrument Company. Readings from these sensors have a claimed accuracy of $\pm 2^{\circ}\text{C}$.

Four such temperature sensors were used, taped to a plastic pipe which was then forced into the tailings. The sensors were spaced at 0.6 metre intervals with the lowest sensor approximately 0.2 metres above the filter blanket.

The upper two sensors were therefore initially above the tailing surface, as shown on Figure 3.4. Approximately 600 mm of additional ice and tailings was added to Site B between mid January and mid-February 1985.



3.9.2 Site A Phreatic Surface

To observe the elevation of the phreatic surface in the tailings and the filter blanket in the vicinity of Site A, four standpipes, designated SP1-A to SP4-A were installed in November 1984, as shown in Figure 3.2. The water depth in the standpipes was determined using a portable well probe.



SECTION 4.0 - ATMOSPHERIC DATA

4.1 OBJECTIVES

Atmospheric monitoring equipment was installed at Site A for comparison with data collected at the KLMC climatological station, and for estimating the evaporation from the exposed tailings surface. This information is required to complete water balance calculations for the tailings facility.

A number of formulae are available to estimate evaporation. The most reliable of these is the combination (Penman energy budget) method which uses station data of air temperature, humidity, sunshine hours and wind speed (Linsley et al). The potential evaporation, E is given by:

$$E = H \cdot \frac{\Delta}{\Delta + \gamma} + E_a \frac{\gamma}{\Delta + \gamma} \text{ mm/d.}$$

where H = net radiation (mm/d)

E_a = aerodynamic evaporation (mm water/d)

Δ = slope of saturated vapour pressure curve (mb/°C)

γ = psychrometric constant (mb/°C)

For this phase of the study it was not possible to carry out meaningful evaporation calculations due to the late start-up of the complete monitoring programme and ensuing winter conditions. Future work would be aimed at collecting suitable station data during the evaporation season, and correlating Site A data with that collected at the KLMC climatological station.

The KLMC station is located at latitude 57° 12'N and longitude 105° 40' W at an elevation of 550 metres. Site A is approximately 7 km to the south-west at an elevation of 544 metres. Monthly Climatological Station Reports



for Key Lake (KLMC station) are included in Appendix B, as Tables B1 to B9. Also included are Tables B10 to B16 summarizing weather data accumulated from Site A by the data logger.

A month by month comparison of climatological data is included as Table 4.1.

4.2 TEMPERATURE

Average daily air temperatures for Site A are plotted on Figure 4.1. For reporting purposes the average daily temperature is calculated as the mean of all valid readings recorded during a 24 hour day commencing at 8 a.m. Daily averages were below zero for the entire November to March period. Four short periods of near thawing temperatures were observed during this time. The coldest minimum recorded by the KLMC station during the period of monitoring was -55°C .

4.3 PRECIPITATION

Negligible precipitation was recorded at Site A although the quantities measured by the KLMC station are significant, as shown on Table 4.1. The rain gauge installed at Site A, although a respected industry standard capable of measuring snowfall, would require wind shielding and improved design of the heating and insulation to operate under gusty and extremely cold conditions. For calculation of the water balance in Section 6.3 data from the KLMC station was used.

4.4 RELATIVE HUMIDITY

Daily averages for relative humidity, calculated similarly to temperature, are plotted for November and December on Figure 4.2. Further data was not recorded as there was no need for the data over the winter period.



TABLE 4.1

KEY LAKE PROJECT
MONITORING OF LAYERED URANIUM TAILINGS - PHASE 1

CLIMATE DATA FROM KEY LAKE CLIMATOLOGICAL STATION AND SITE A

	AUGUST		SEPTEMBER		OCTOBER		NOVEMBER		DECEMBER		JANUARY		FEBRUARY		MARCH	
	KLMC	Site A	KLMC	Site A	KLMC	Site A	KLMC	Site A	KLMC	Site A	KLMC	Site A	KLMC	Site A	KLMC	Site A
Mean Temperature °C	16.3	-	6.0	-	0.0	3.4	-16.5	-15.2	-27.1	-27	-23	-27	-27	-27	-13.0	-12.1
Maximum Temperature °C	32.0	-	19.0	-	22.5	22.3	1.5	0.4	2.0	0.7	4.5	3.0	-2.0	1.4	+2.0	-4.9
Minimum Temperature °C	2.5	-	-6.0	-	-21.0	-20.6	-37.5	-27	-55	-27	-46	27	-45	-27	-31	-27
Total Rain (mm)	61	-	23.2	-	30.1	3.3	0.3	0	1.7	0	0	0	0	0	0	0
Total Snow (cm)	0	-	2.3	-	19.3	0	31.3	0	10	0	32.5	0	17.3	-	1.7	-
Total Precipitation (mm)	61	-	25.5	-	49.4	3.3	31.6	0	11.7	0	32.5	0	17.3	2.0	4.3	0.3
Days with Precipitation	14	-	16	-	17	1	17	0	11	0	9	0	11	2	2	1
Evaporation (Net) mm	160.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Wind Run (km)	10636	-	9613	-	12706	-	7760	-	9953	8385	7957	6704	8279	7201	2432	2096
Average Speed (km/h)	14.3	-	13.4	-	17.1	-	10.8	-	13.4	11.3	10.7	9.0	12.3	10.7	11.3	9.7
Maximum 24 Hrs. (km)	708	-	851	-	697	-	355	-	737	519	691	488	625	521	520	398
Maximum 1 Hr. run (km)	44	-	45	-	37	-	26	-	35	30	39	31	45	40	35	27

Notes: ° Data for part month only

- No data collected

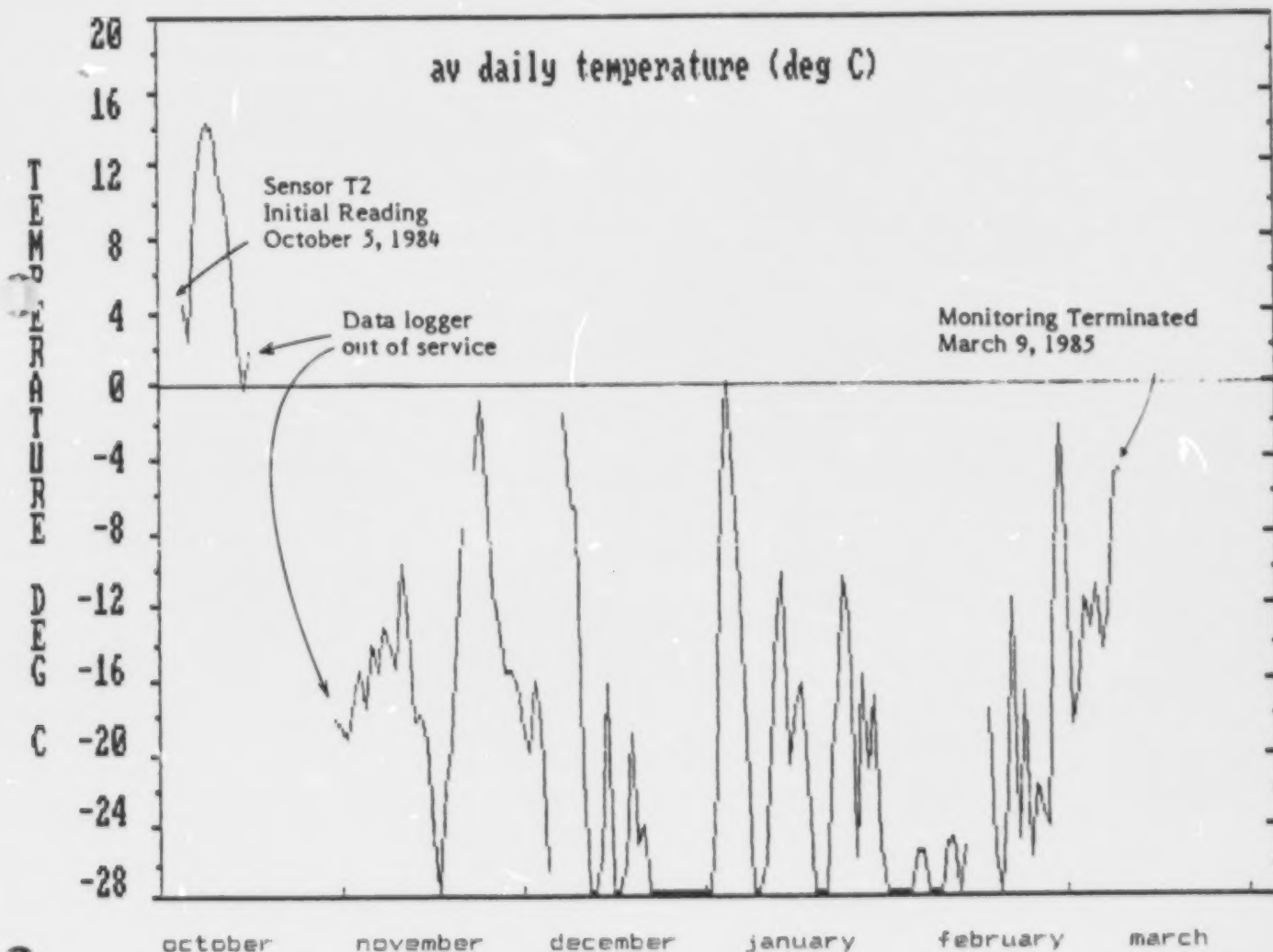
(1) -27 for Site A temperature denotes less than or equal to -27°C.

(2) For Site A maximum 1 hour wind run is maximum scanned value of wind speed for month.

(3) Wind run gauges for KLMC and Site A were 13 metres and 2 metres above ground respectively.

Knight & Piesold Ltd

KEY LAKE PROJECT
MONITORING OF LAYERED URANIUM TAILINGS - PHASE 1
DATA SUMMARY - TEMPERATURE
Average Daily Atmospheric Temperature



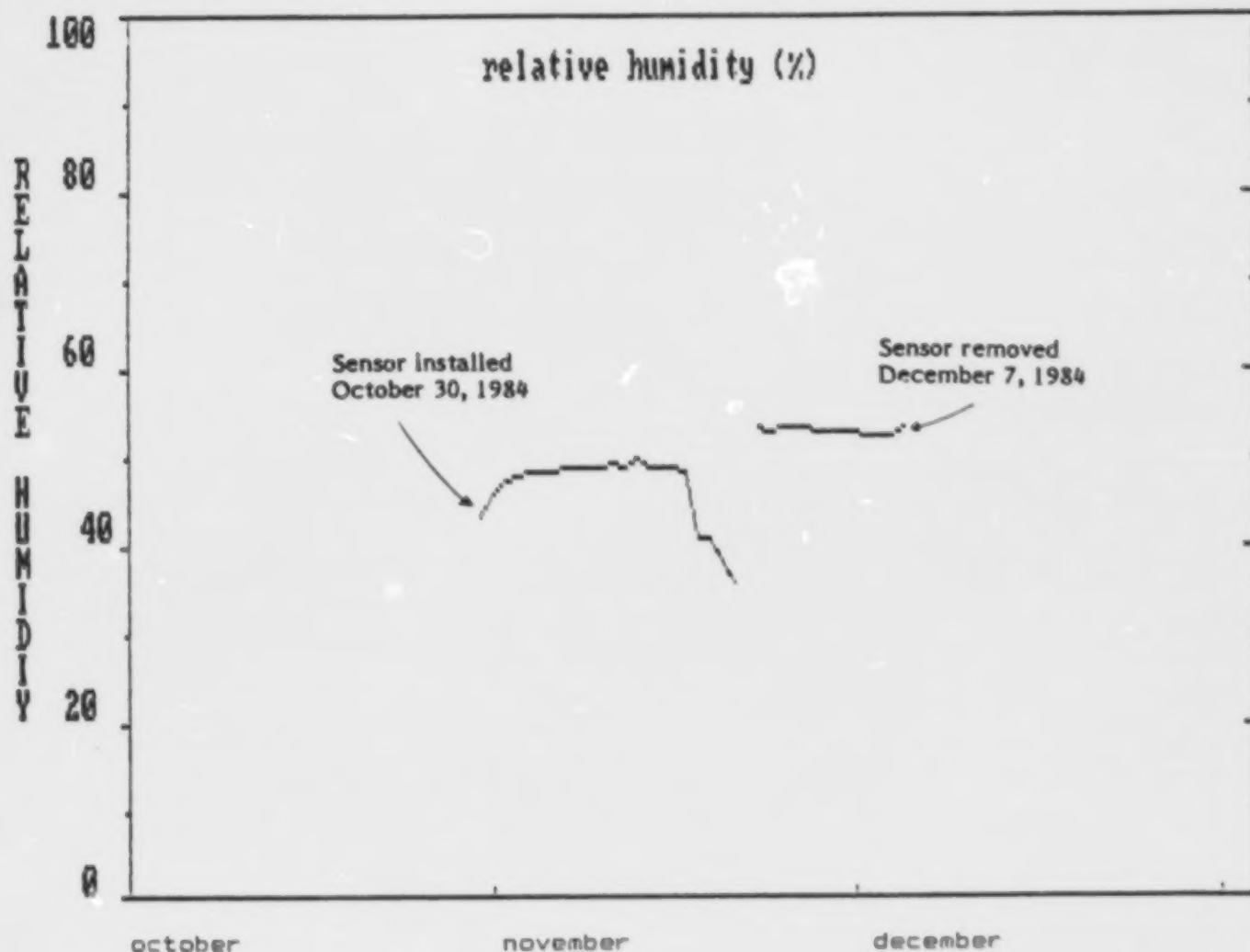
Note: Data is average of all daily readings collected within 24 hour day beginning at 8 a.m.

Temperatures below -28°C were not accurately recorded by the data logger.

FIGURE 4.1

Knight & Piesold Ltd

KEY LAKE PROJECT
MONITORING OF LAYERED URANIUM TAILINGS - PHASE 1
DATA SUMMARY - RELATIVE HUMIDITY
Average Daily Relative Humidity



Note: Value plotted is the daily average of readings within 24 hour period beginning at 8 a.m.

FIGURE 4.2

4.3 WIND RUN

Average daily wind run is reported as the total of 24 measurements of wind speed made at hourly intervals during a day commencing at 8 a.m. The maximum observed wind speed at Site A was 39.6 kph on February 28 and the greatest daily wind run was 521 km on February 27. Average wind speeds at the KLMC station were generally higher than at Site A. This could reasonably be expected due to the greater elevation of the KLMC sensor. Variation also has partially resulted from the location of the Site A wind sensor close to the north embankment of the tailings facility. Wind run recorded at Site A is plotted on Figure 4.3, and for comparative purposes against KLMC station data on Figure 4.4.

4.6 SOLAR INSOLATION

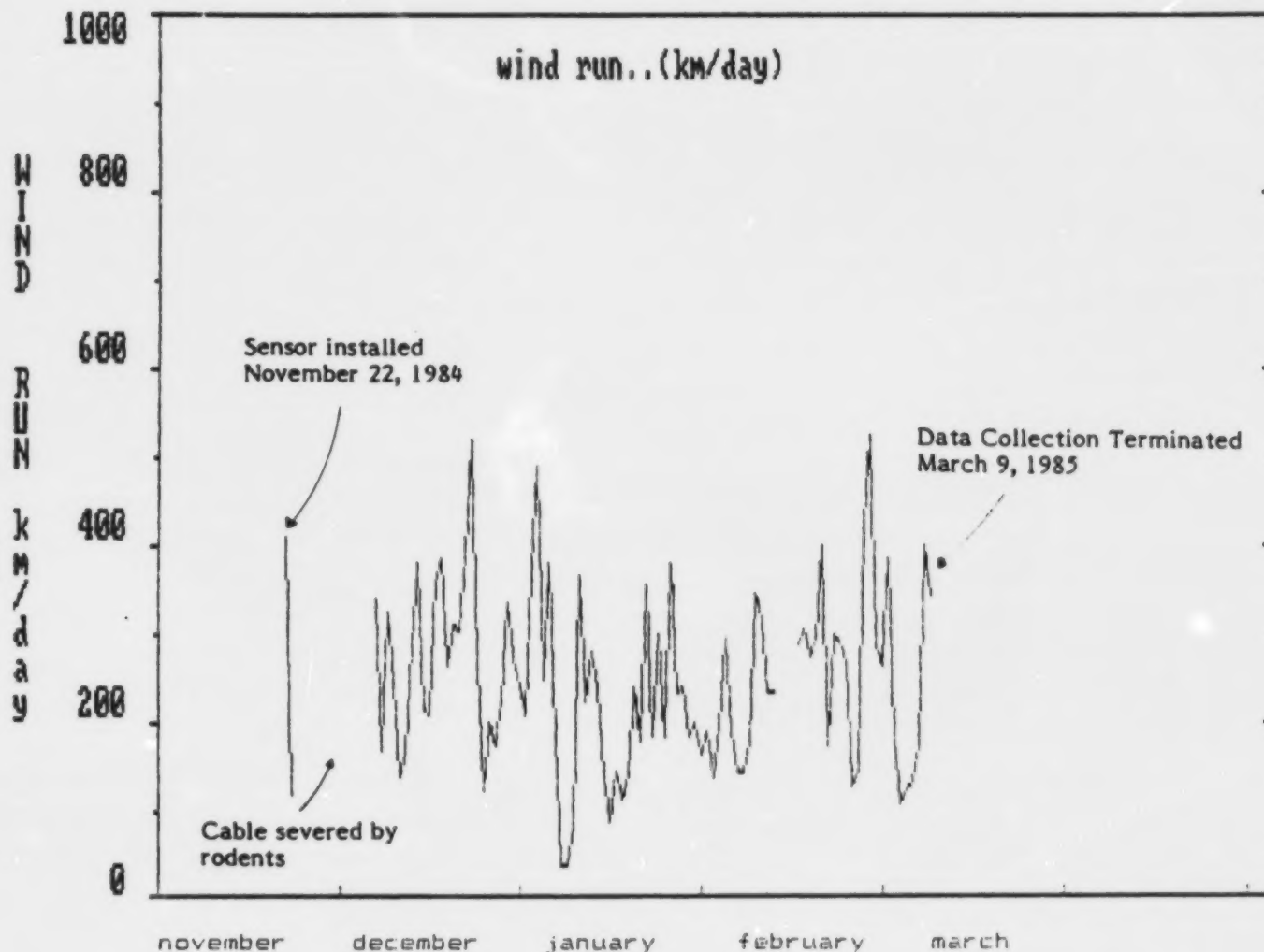
Total daily solar insolation is reported as the total of 24 readings at hourly intervals during a day, commencing at 8 a.m., with each reading reduced by the lowest reading recorded each day which is assumed as the zero error. Daily solar insolation is plotted on Figure 4.5.

A steady decrease was noted from October with a minimum during December, rising steadily until termination of monitoring in March. Normal scatter of the data about the trend line is the obvious function of relatively cloudy or bright days. From time to time the instrument was completely covered by fresh snow and under freeze-thaw conditions by water droplets or ice lenses.

The average monthly solar insolation monitored at Site A was compared with the theoretical maximum clear sky values for the latitude of Key Lake on Figure 4.6.

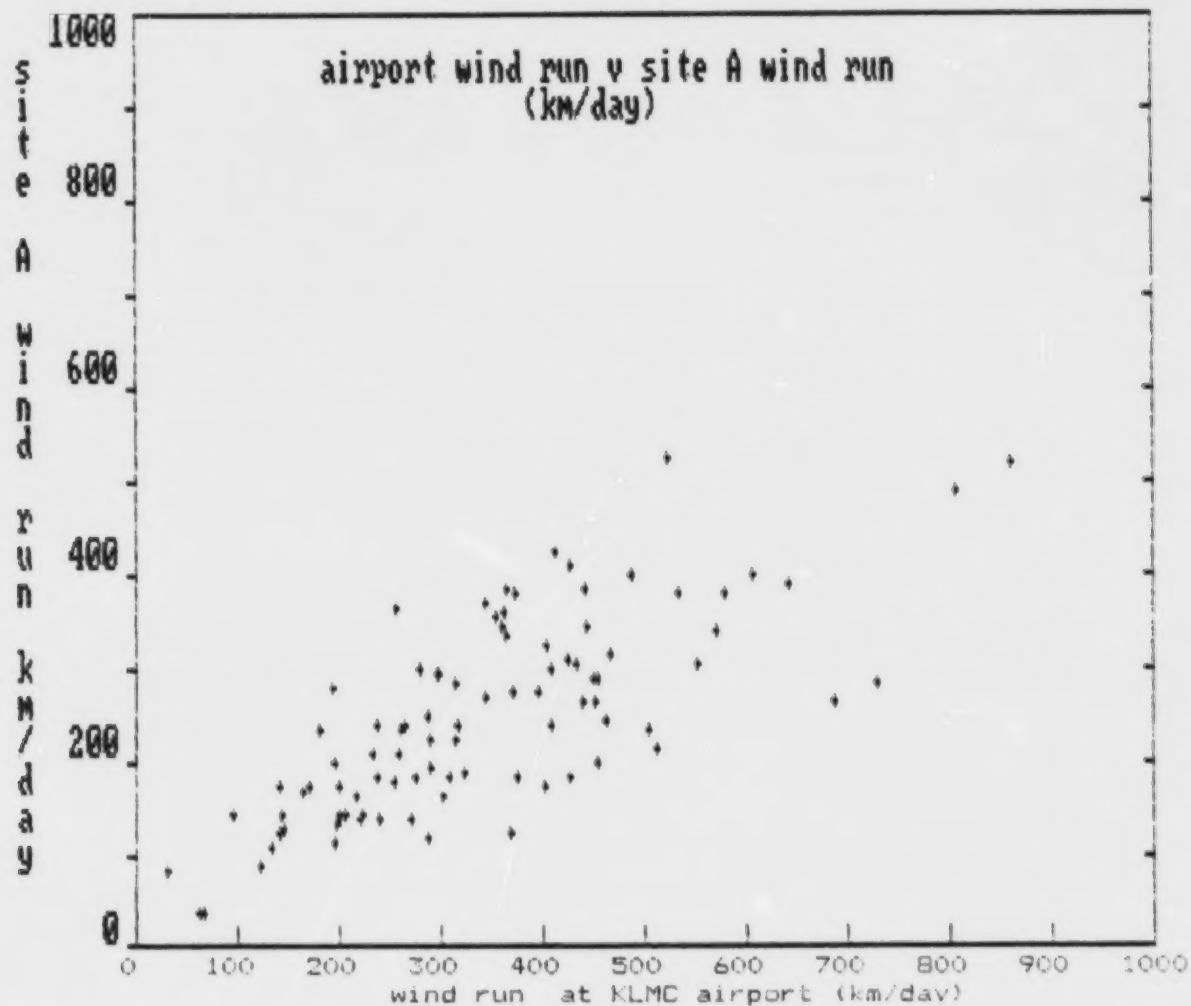


KEY LAKE PROJECT
MONITORING OF LAYERED URANIUM TAILINGS - PHASE 1
DATA SUMMARY - WIND RUN
Daily Wind Run



Note: Values plotted are effectively the sum of 24 readings taken at one hourly intervals.

MONITORING OF LAYERED URANIUM TAILINGS - PHASE 1
correlation of wind speed at airport and site A



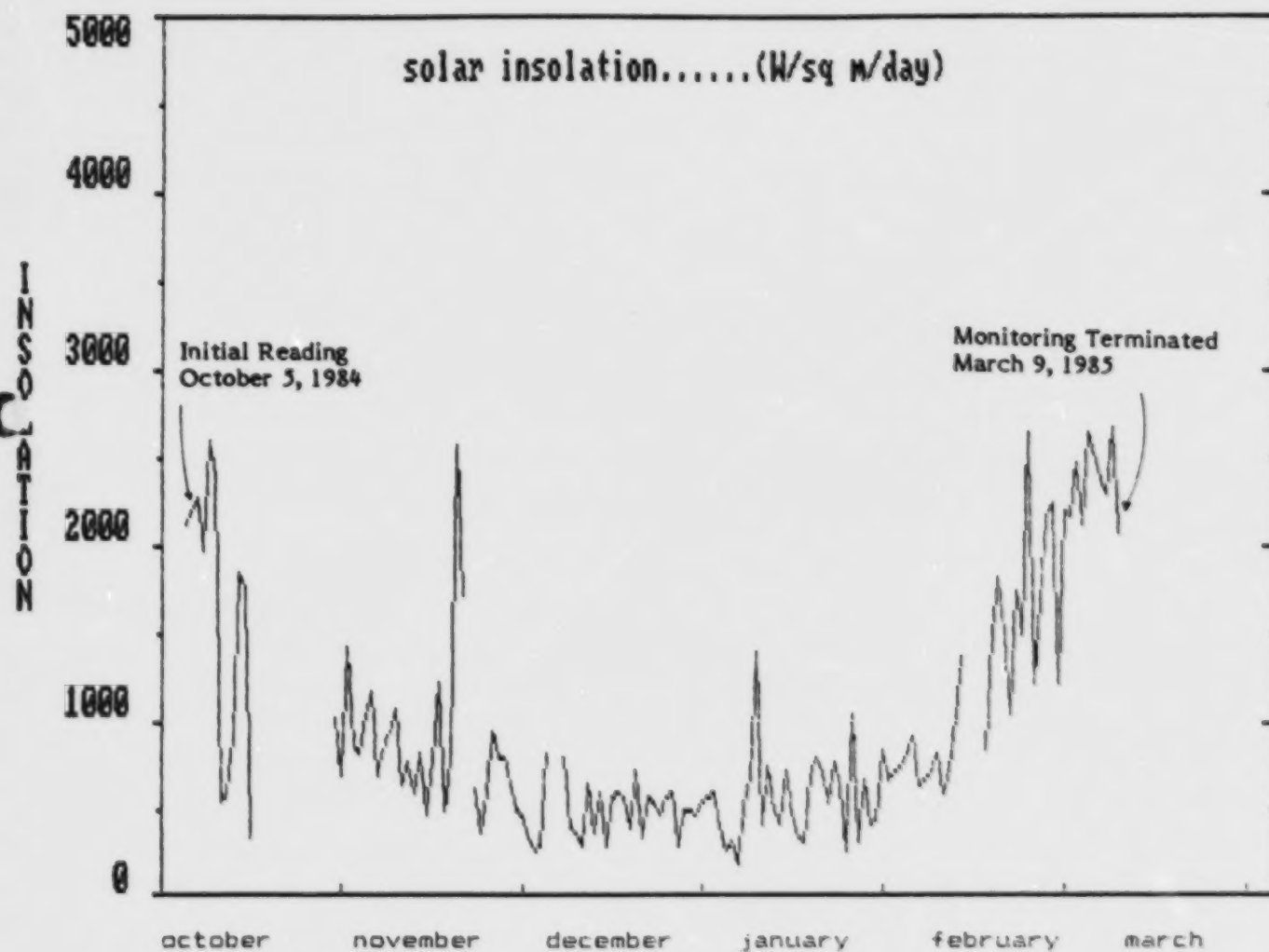
Notes...

airport wind run gauge at elevation 13 metres

site A wind run gauge at elevation 2 metres

Knight & Piesold Ltd

KEY LAKE PROJECT
MONITORING OF LAYERED URANIUM TAILINGS - PHASE 1
DATA SUMMARY - SOLAR INSOLATION
Total Daily Solar Insolation

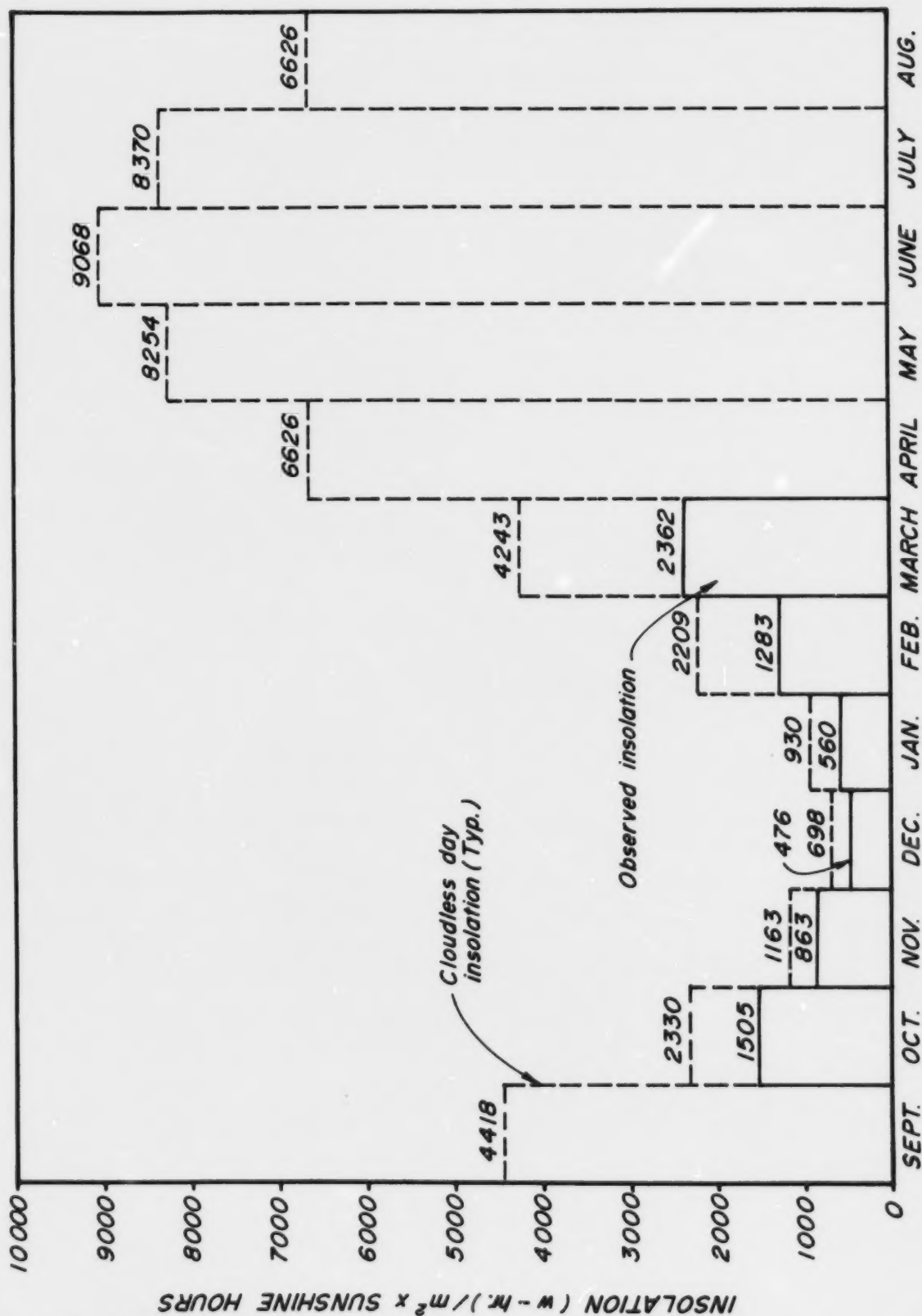


Note: Values plotted are effectively the sum of 24 readings taken at one hourly intervals.

FIGURE 4.5

MONITORING OF LAYERED URANIUM TAILINGS - PHASE I

COMPARISON BETWEEN OBSERVED SOLAR INSOLATION AND THEORETICAL MAXIMUMS
(DAILY MEAN ($W/m^2 \cdot day$) ON A MONTHLY AVERAGE BASIS)



Knight and Pietsold Ltd.

CONSULTING ENGINEERS

As expected, due to cloud cover, the monitored values are lower than the theoretical maximums and would allow an estimate to be made of the proportion of solar insolation reaching the tailings facility each month. This information may be used in calculation of the evaporation from the tailings surface.

References

Linsley R.K., Kohler M.A., Paulhus J.L.M: "Hydrology for Engineers", McGraw-Hill, 1975.



Association
of Consulting
Engineers
of Canada

Association
des Ingénieurs-
Conseils
du Canada

SECTION 5.0 - TAILINGS PHYSICAL DATA

5.1 SURFACE CONDITIONS

A general chronology of observations of tailings deposition, surface conditions and program of field work during this study is included on Table 5.1.

In summary approximately 1.2 metres of tailings were placed over the test Site A prior to commissioning of any equipment. By mid October, several weeks after commissioning, the tailings depth had increased to 2.0 metres after which time no further tailings were placed over Site A during the study. Freezing of both sites began in late October and by mid March the frozen tailings were approximately 350 mm deep at Site A, and estimated at 1000 mm deep at Site B. Snow cover was variable, being subject to wind shift, but the depth at Site A was approximately 600 mm in mid March.

5.2 PORE PRESSURE MONITORING

Variations in pore pressure transducer readings at Site A are included in Appendix B as Tables B17 to B22 and summarized on Figures 5.1 to 5.4. The fall in transducer readings is compared to observed water levels in the standpipes on Figure 5.5. Actual standpipe elevations are tabulated in Appendix B, on Table B23. As previously noted, pore pressure readings reported by the transducers should be regarded as indicative of trends, with the standpipes providing accurate readings of pore pressures at the base of the tailings.

Monitoring of pore pressure transducers began in early October during the last week of tailings deposition over Site A. During this period an expected rise in pore pressure was recorded, as indicated on Figures 5.1 and 5.2. For the next six to eight weeks considerable fluctuation was observed but in



TABLE 5.1

KEY LAKE PROJECT
MONITORING OF LAYERED URANIUM TAILINGS - PHASE I

VISUAL OBSERVATIONS OF TEST SITES

<u>DATE</u>	<u>OBSERVATIONS</u>
July	Work on temporary confining embankment in south west corner of tailings storage facility completed. Estimated 500,000 m ³ of water ponded along eastern edge of facility covering approximately 30% of the surface area.
	Underseal, drains and piping installed at Site A.
	Deposition of tailings commenced into temporary confining area, this being the first use ever of this section of the facility.
August 1-10	Piezometers Number P43 and P46 installed at Site A.
September 10-20	Monitoring hut, weather instruments and data logger brought to site and installed. Tailing deposition continuing over Site A. Total tailings depth estimated at 1200 mm.
October 2-6	Fresh tailings being deposited over Site A with intermittent flow. Estimated tailings depth 1800 mm. Weather generally overcast and cool. Installed flow meter, connected piezometer P43 and P46 to data logger.

- 2 -

Access scaffolding installed at Site B on south side of facility. Temperature probes installed at Site B.

October 15-18

Tailings discharge moved to south corner of temporary confinement with flow partly into temporary confinement and partly into remaining facility. Flow over Site A estimated to have ceased one week before this visit. Cracking of tailings observed upstream and downstream of Site A. No foot access available to Site A. Estimated tailing depth of 2000 mm. Some overnight snow and freezing conditions with full thaw by mid-day. Windy and wet.

Installed moisture density access tubes at Site B.

Microscout data logger removed to Vancouver for repair and modification.

October 29-30

Data logger returned to Site. Weather cold with snow. Both sites snow covered. Tailing deposition continuing from south corner of temporary area with most flow spilling over onto older tailings in south half of facility.

November 19-23

Site A surface frozen with 100 mm ice and 300 mm of snow cover. Temperatures below freezing at all times. Installed temperature sensors T1, T3 and T4 and pore pressure sensors P42 and P44 at Site A. Installed wind speed gauge, standpipes and moisture density tubes at Site A. Obtained core samples for geotechnical evaluation, mineral identification and leach tests. Repairs made to rodent damaged cables.

- 3 -

November 19-23 Tailings discharge now located from emergency discharge pipes at centre of facility. Meandering, streaming, and delta pattern observed.

Removal of ponded water from eastern end of tailings storage facility for treatment in ion exchange had commenced.

December 5-7 Weather mostly clear and cool, snow flurries and rain. On site modifications to microscout and repairs to rodent damaged sensor cables.

January 7-11 Tailings discharge continued from centre of facility with a general pattern of rapid flow down the beach without freezing. Weather clear and cool with daily highs around -20°C .

Approximately 420 mm snow at Site A and 1200 mm at Site B. Ice depth of 240 mm at Site A and 600 mm (estimated from temperature measurement) at Site B. Site B continually in shade.

February 11-15 Tailings discharge continued from central discharge point with delta formation and flow over entire south half of facility. Approximately 600 mm of additional frozen material over Site B since last visit.

Weather generally clear and cool with variable cloud and wind.

Snow depth at Site A 525 mm and zero at Site B. Ice depth at Site A 350 to 500 mm and possibly 1000 mm at Site B.

- 4 -

Deformation of Moisture/Density probe access pipes prevented complete data collection at both Sites.

March 8-11

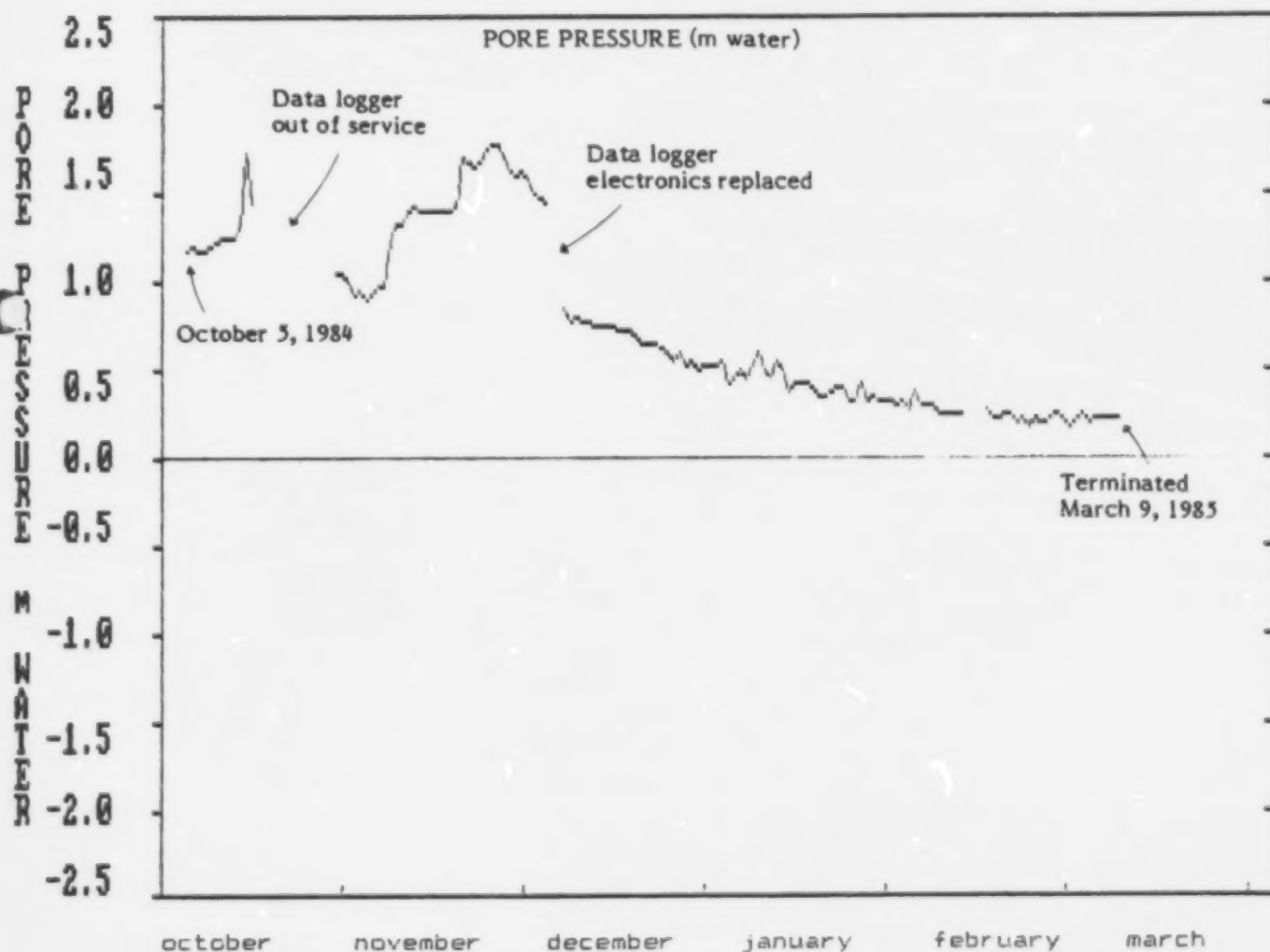
Continued tailings discharge from central point has form elevated hump. Flow streaming to north east corner of facility. Ponded water largely gone from eastern toe of facility. Winter tailings discharge strongly humped and ridged with radial pattern from central discharge point. Thawing trend in weather with strong winds.

Snow depth 600 mm at Site A and 400 mm at Site B. Ice depth 350 mm at Site A and 1000 mm estimated at Site B. Temperature observations suggest a warm flow of water under Site B.

Microscout data logger removed March 10 for shipment to Vancouver.

Knight & Piesold Ltd

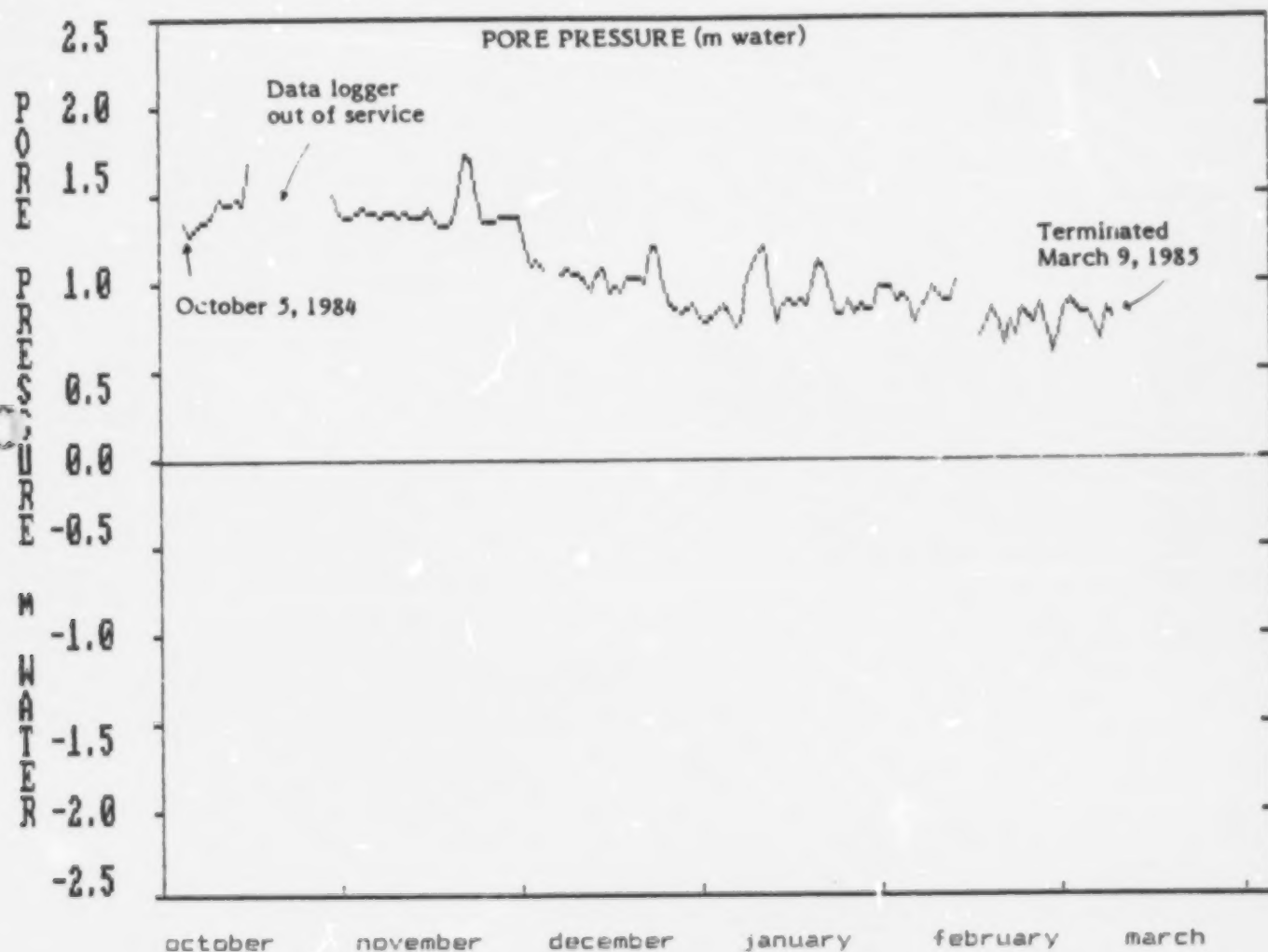
KEY LAKE PROJECT
MONITORING OF LAYERED URANIUM TAILINGS - PHASE 1
DATA SUMMARY - PORE PRESSURE
Daily Average Pore Pressure (Unit P 43)



Note: Absolute values of pore pressure are not accurate.

Inglot & Plesold Ltd

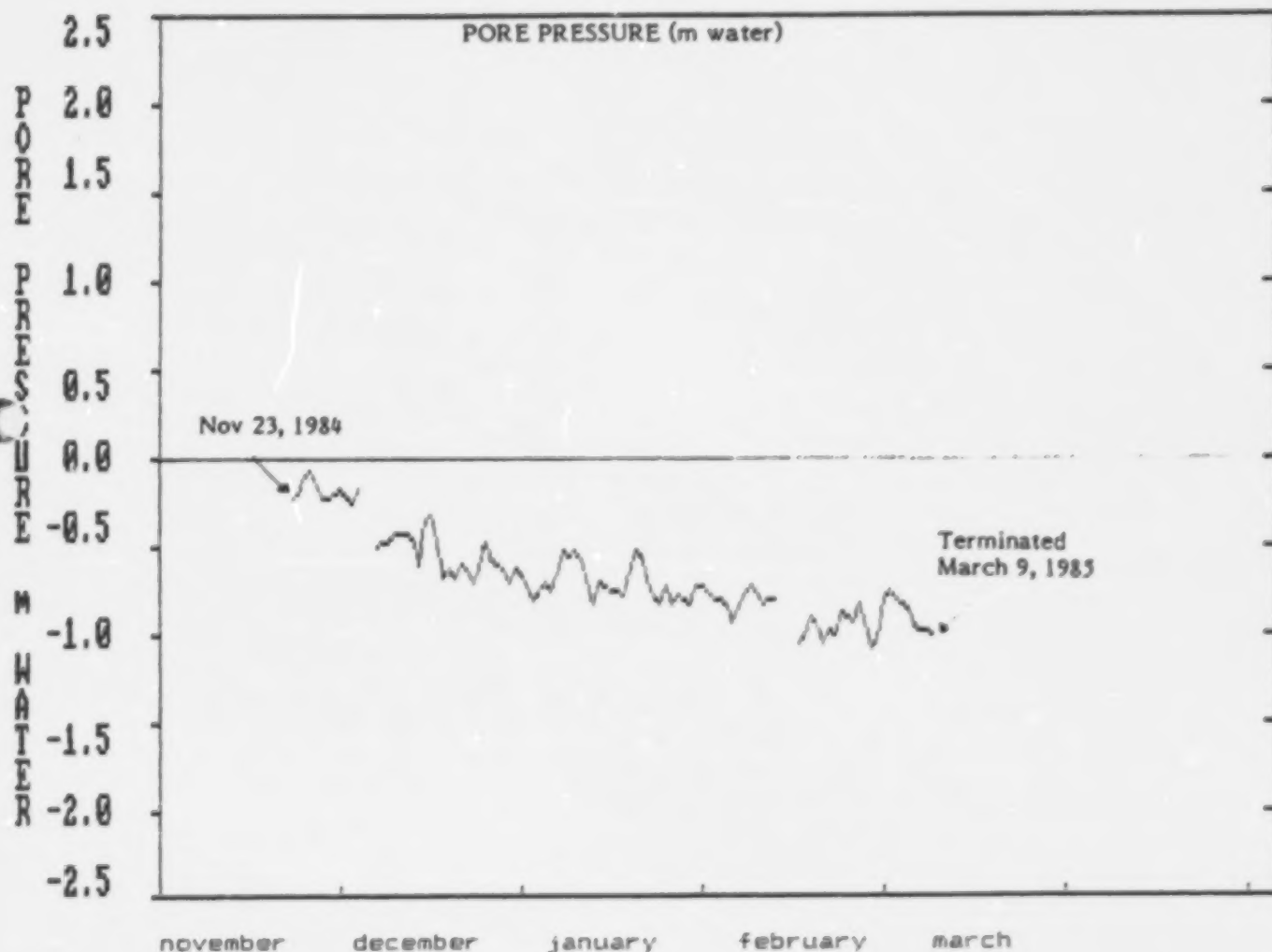
KEY LAKE PROJECT
MONITORING OF LAYERED URANIUM TAILINGS - PHASE 1
DATA SUMMARY - PORE PRESSURE
Daily Average Pore Pressure (Unit P 46)



Note: Absolute values of pore pressure are not accurate.

FIGURE 3.2

KEY LAKE PROJECT
MONITORING OF LAYERED URANIUM TAILINGS - PHASE 1
DATA SUMMARY - PORE PRESSURE
Daily Average Pore Pressure (Unit P 42)



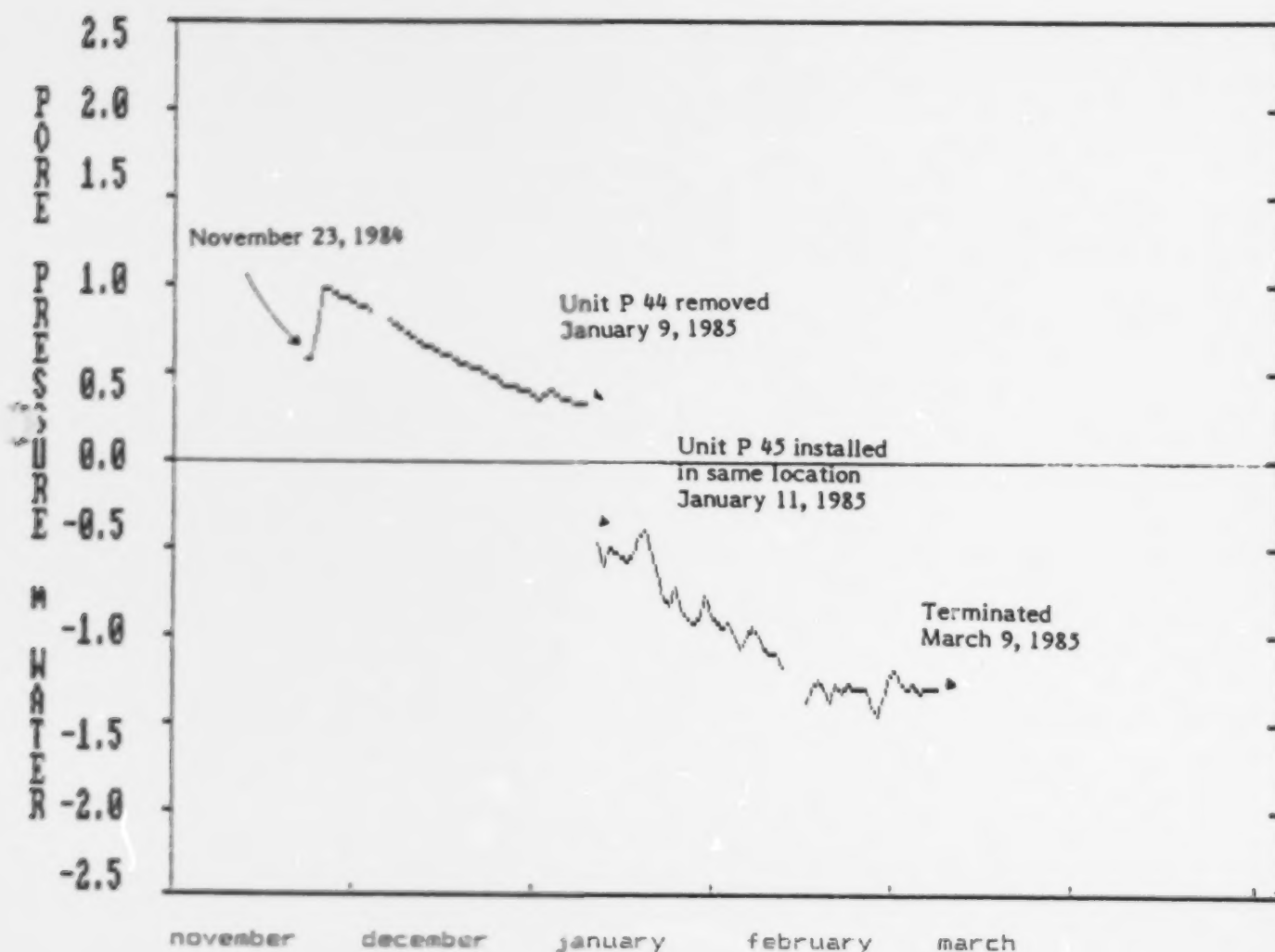
Note: Absolute values of pore pressure are not accurate.

03-19-1985

FIGURE 5.3

Ingham & Fildes Ltd

KEY LAKE PROJECT
MONITORING OF LAYERED URANIUM TAILINGS - PHASE 1
DATA SUMMARY - PORE PRESSURE
Daily Average Pore Pressure (Units P 44/P 45)



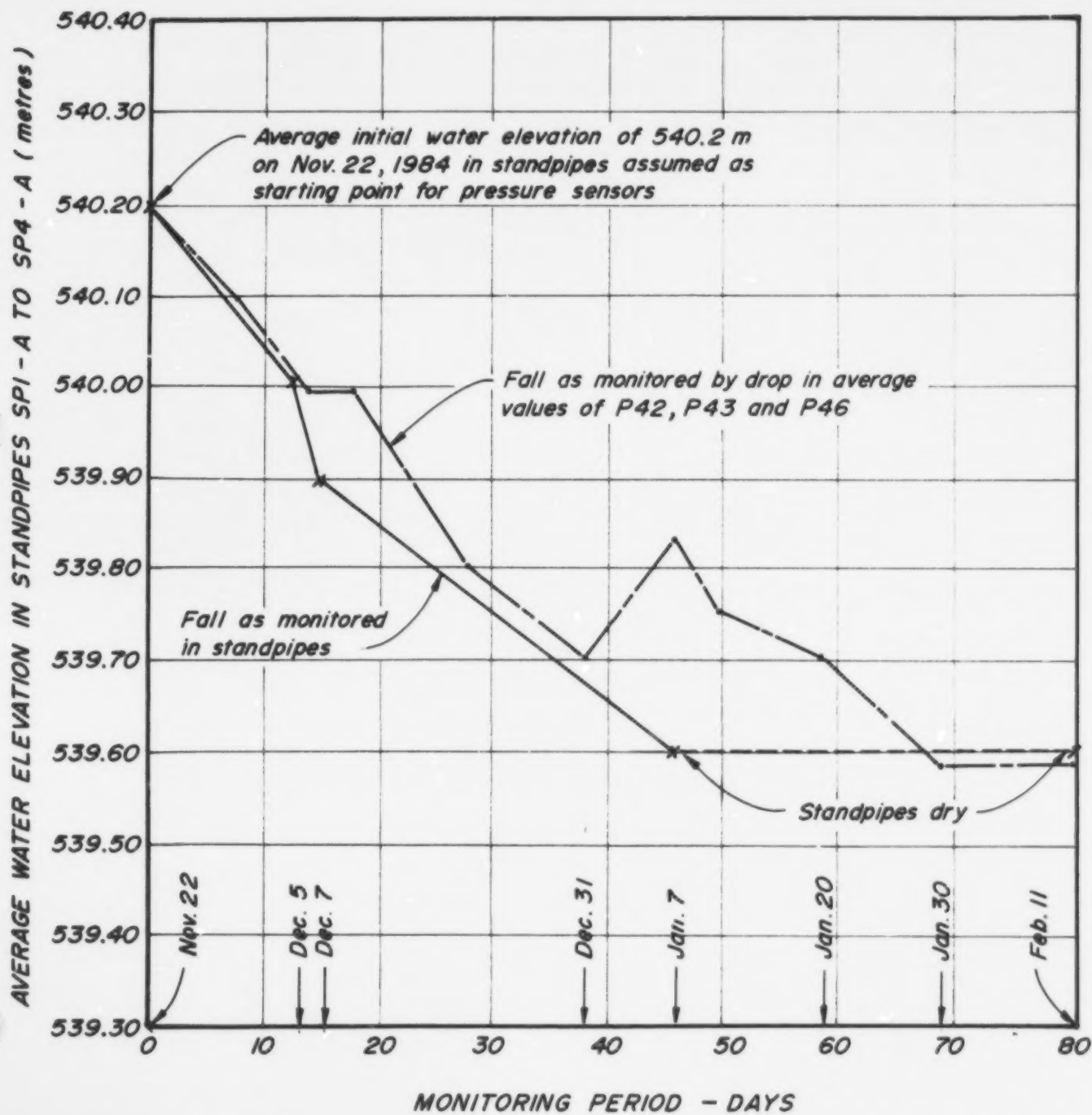
Note: Absolute values of pore pressure are not accurate.

03-19-1985

FIGURE 3.4

MONITORING OF LAYERED URANIUM TAILINGS - PHASE I

FALL OF PHREATIC SURFACE AT SITE A



general the transducer readings remained constant or increased for much of this time. These observations coincide with the high phreatic surface observed in the standpipes on November 22nd.

A fall in the phreatic surface was observed from November 22 in both the transducers and standpipes, as shown on Figure 5.5. The fall was quite rapid, and standpipes at the base of the tailings were dry when observed on January 7th. At this point the tailings were essentially drained of free water and a slow continued fall in pore pressure was observed in all transducers until essentially constant readings were observed at the end of the monitoring period.

5.3 TEMPERATURE PROFILES AND FROST PENETRATION

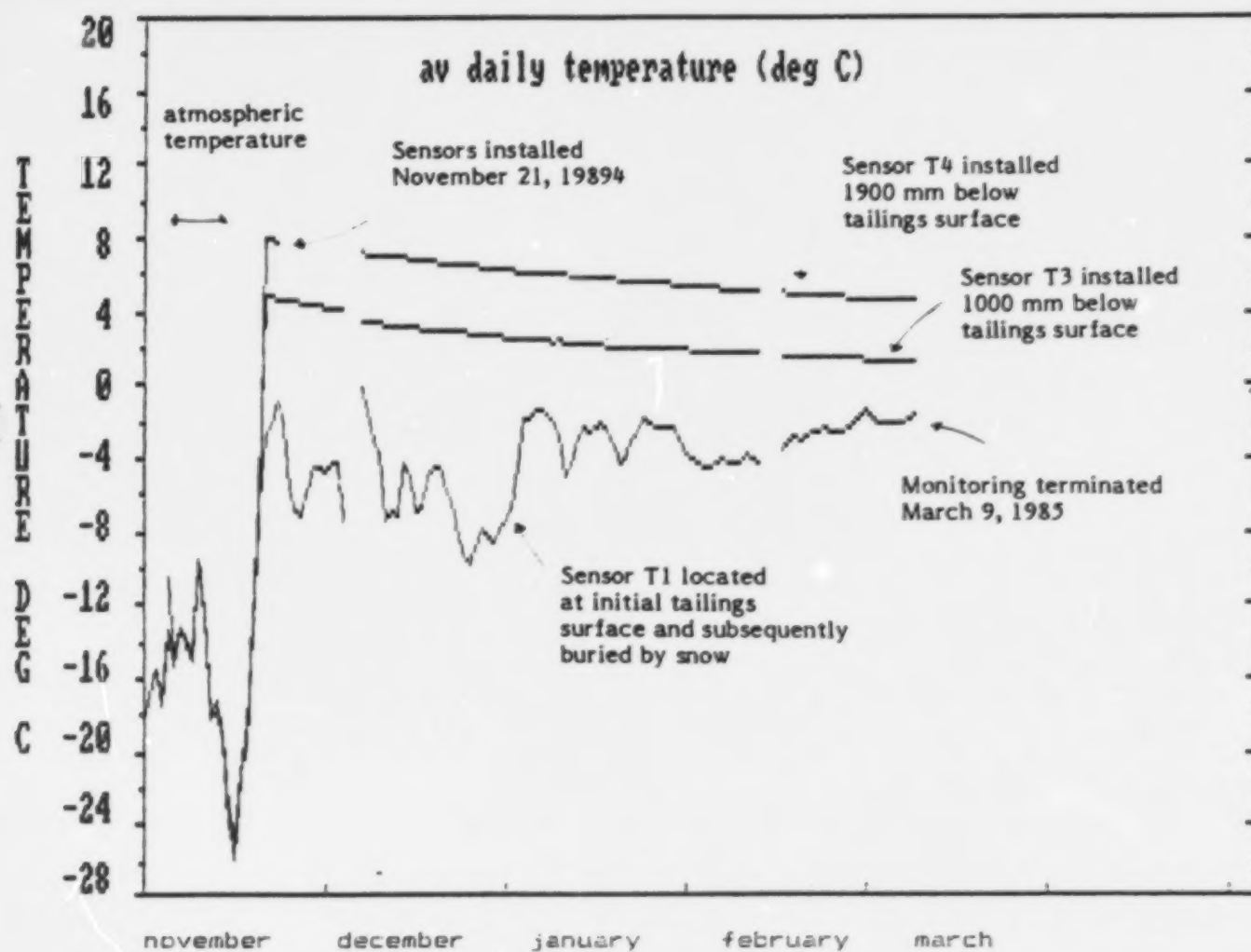
Temperature sensor readings for the tailings at Site A and Site B are plotted on Figures 5.6 and 5.7 respectively. Additional data and observations related to ice thickness and tailings temperature are provided in Table 5.1, and in Appendix B on Tables B17 to B22 and B24.

At Site A, the maximum ice depth observed during the monitoring period from November 21 to March 9 was 500 mm, which occurred in mid February. The temperature 1000 mm below the initial tailings surface reached a low of 1.3°C , and that 1900 mm below the surface a low of 4.9°C . The rate of decrease over the observation period was less than 1°C per month.

Beginning in July 1984, 2 metres of partly drained and settled tailings were placed over Site A in the space of approximately 3 months, probably retaining a high sensible heat budget. These tailings were then covered with an insulating snow blanket, prior to any significant exposure to freezing conditions. Thus the depth of frost penetration may be lower than would occur with the same thickness of tailings deposited at a slower rate.

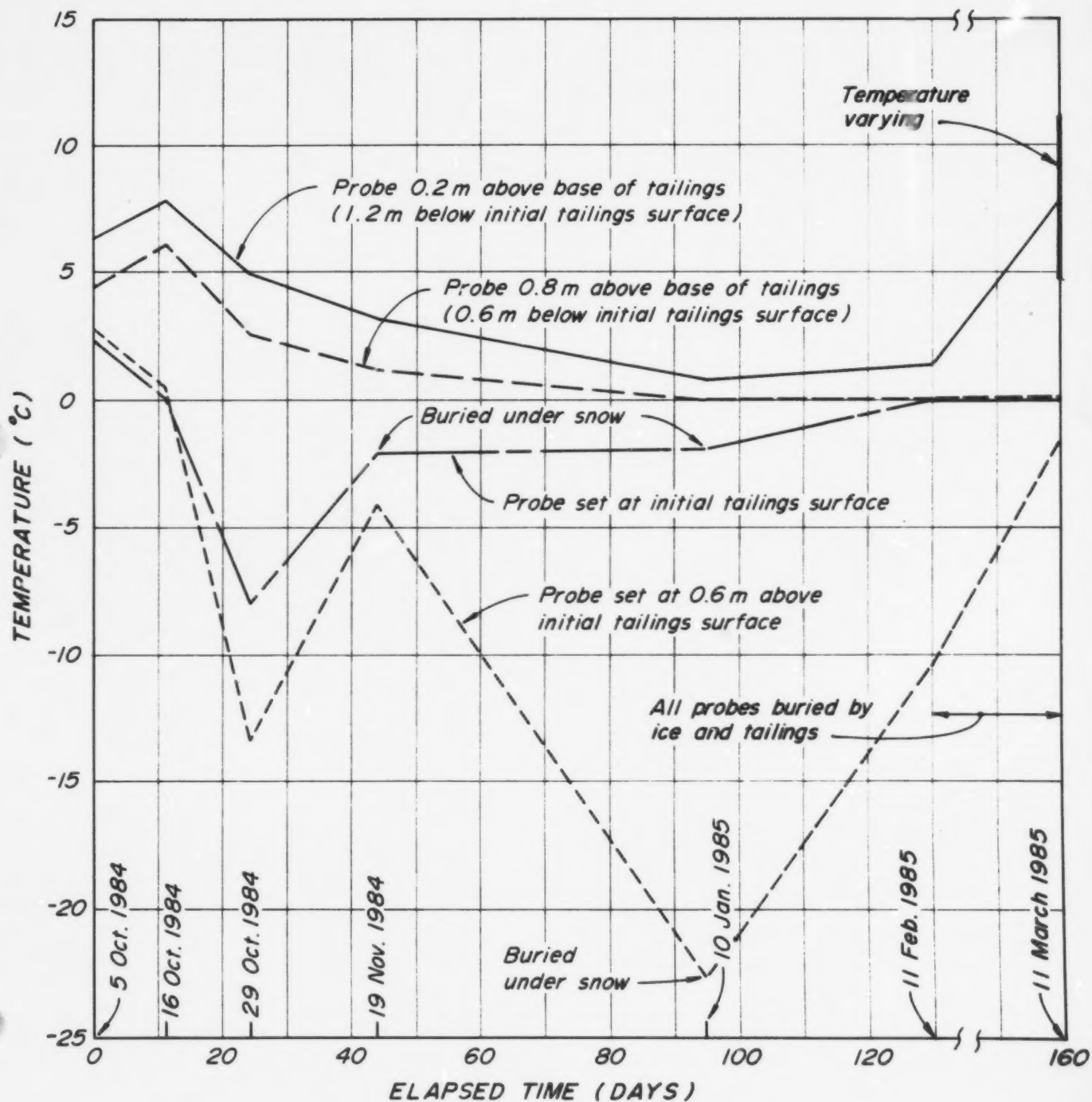


KEY LAKE PROJECT
MONITORING OF LAYERED URANIUM TAILINGS - PHASE 1
DATA SUMMARY - TEMPERATURE
Tailings Temperature Site A



Note: Depth of tailings at installation of Sensors was approximately 2.0 metres.
Sensor T2 was used for atmospheric temperature monitoring.

KEY LAKE PROJECT
MONITORING OF LAYERED URANIUM TAILINGS - PHASE I
SITE B TEMPERATURE PROFILE



By contrast, at Site B freezing temperatures were recorded 600 mm below the initial tailing surface. With the addition of 600 mm of frozen ice and tailings over the initial surface the frost depth at Site B may have reached at least 1.2 metres. The initial tailings at this site had been deposited the previous winter and thawed during the ensuing summer. This fact, together with the location in the shade of the south embankment, probably ensured a low sensible heat budget at the on-set of freezing conditions. Site B could be assumed to provide a reasonable and conservative estimate of potential frost penetration under the winter conditions prevailing over the monitoring period.

During monitoring on March 9, at Site B there was evidence of rapidly varying temperature in the sensor closest to the underlying filter blanket. This was possibly due to a warm water flow through the filter blanket, originating from the tailings discharge at that time.

5.4 SEEPAGE QUANTITIES

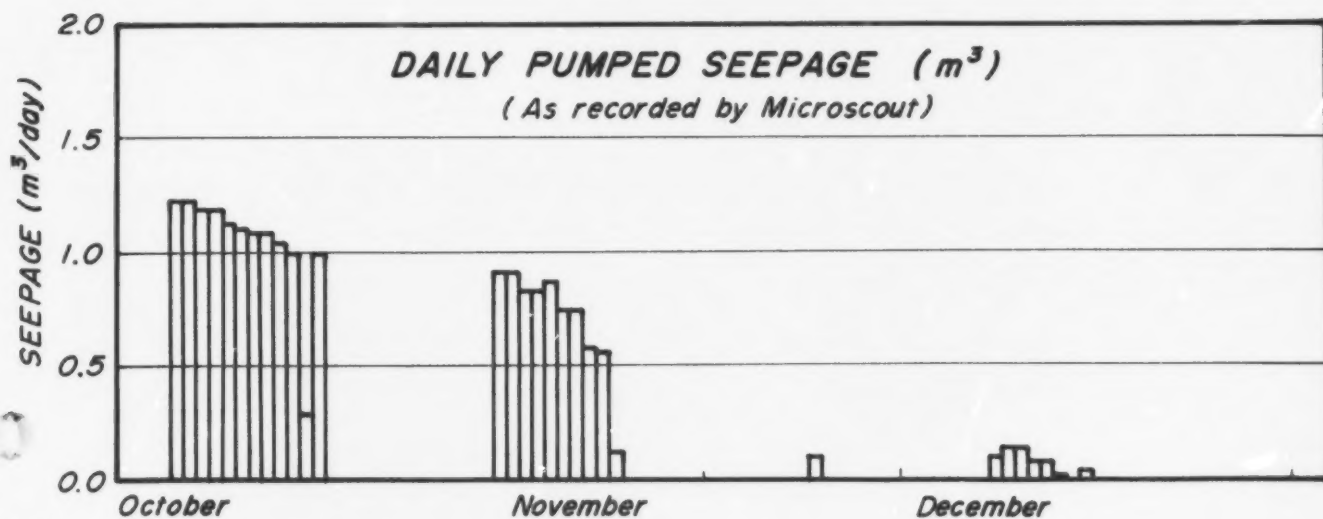
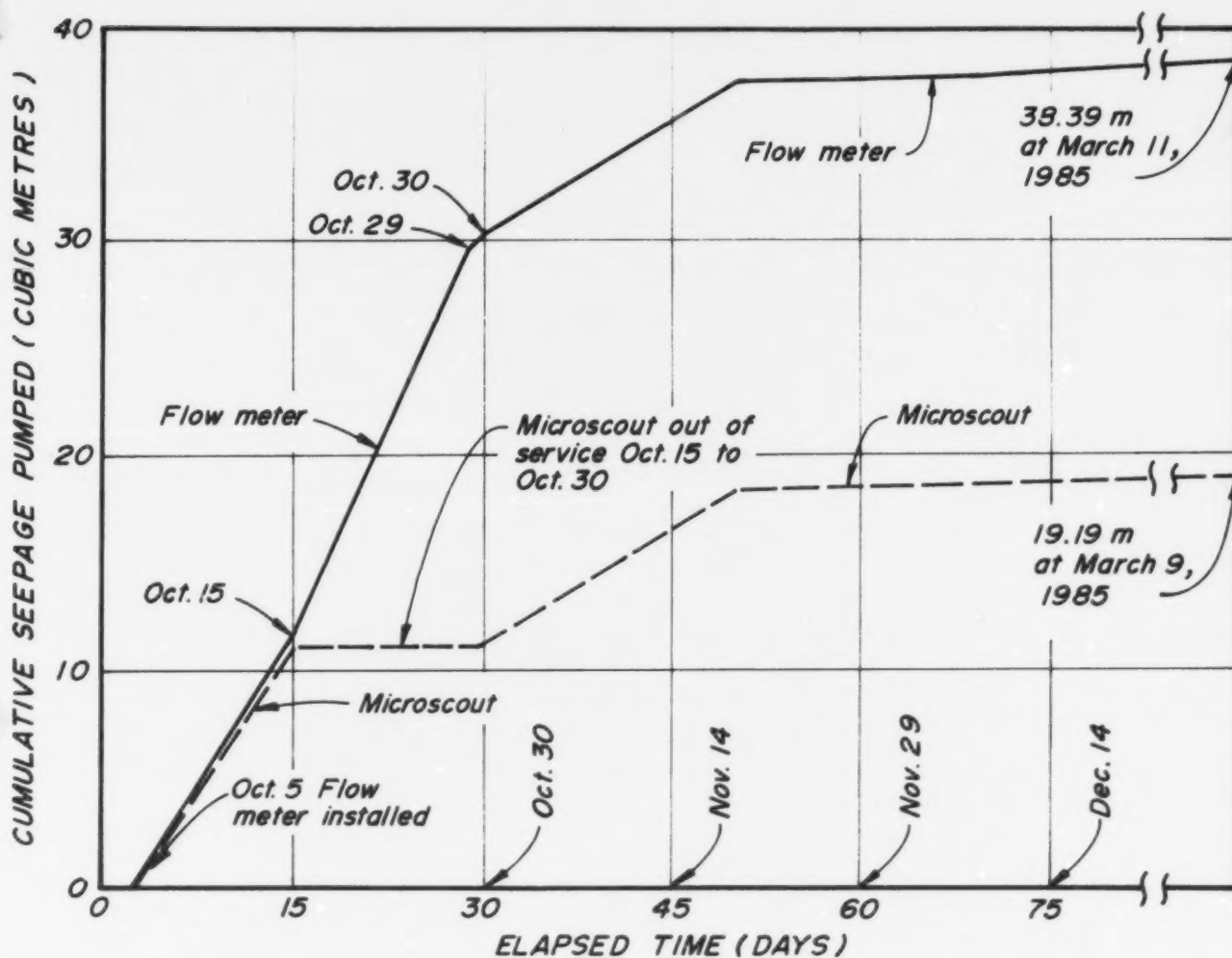
Commissioning of the pump and measurement of seepage from Site A commenced on October 5, 1984. Data from the flow meter totalizer, and the data logger while in operation, are plotted on Figure 5.8 which shows a total of 38 m³ of seepage collected from the test site. Seepage was not monitored from November 23 to December 5 due to an electrical fault in the pump controls. Detailed seepage quantities recorded by the data logger are included on Tables B10 - B16.

As discussed in Section 6.2 the quantity of seepage collected from Site A was approximately 5 times greater than might reasonably have been expected from the tailings at the test site. This large quantity is attributed mainly to seepage into the test site from the surrounding filter blanket.



MONITORING OF LAYERED URANIUM TAILINGS - PHASE I

DAILY PUMPED SEEPAGE



The maximum seepage rate recorded occurred immediately after commissioning at a time corresponding to the high phreatic surface in the tailings. The maximum rate recorded was 1.23 m^3 per day over a surface area of 24 m^2 , corresponding to a seepage rate from the tailings of $5.9 \times 10^{-7} \text{ m}^3/\text{m}^2/\text{s}$.

The seepage rate from the tailings declining progressively with a rapid decline occurring after November 22, again corresponding to the observed rapid fall of the water level in the standpipe piezometers. A small quantity of additional seepage was recorded from December 7 to 14 after lowering of the pump control probes. Minor quantities were recorded thereafter as a result of manually operating the pump.

5.5 THERMOGRAVIMETRIC ANALYSIS (T.G.A.)

Two core samples labelled 2-5 and 3-2 were taken from beneath the ice at Site A at the locations shown on Figure 3.5. The cores, each approximately 300 mm long, were quartered lengthwise and then partially air dried before delivery to B.C. Research for Thermogravimetric Analysis.

Four samples were air-dried by B.C. Research prior to coning and quartering. Representative 50 mg samples were then dried at a controlled rate in air or in nitrogen, with continuous recording of weight losses, up to 600°C .

The tests indicate a significant weight loss of up to 12% at temperatures below normal oven drying temperatures of 105°C . The data also indicates that at least some of this weight loss was derived from non-free water source.

If subsequent work is able to substantiate this finding and better quantify it, one obvious conclusion is that moisture contents of the Key Lake tailings derived by standard oven drying methods must be corrected. Release of



non-free water in standard oven drying methods would have resulted in higher apparent moisture contents.

However, because of the wide variability in the nature of the tailings, low temperature, non-free water losses may also be highly variable, and this factor alone may not allow a single simple correction factor to be applied to apparent moisture contents.

The report by B.C. Research and a discussion of the work carried out are included as Appendix D.

5.6 MOISTURE DENSITY READINGS

Measurements of in-situ density and moisture content were carried out by a combination of core sampling and use of the moisture density gauge. The intent of early core sampling was to calibrate the gauge for these particular tailings, and then use the gauge on an on-going basis for rapid measurement of changes in in-situ density and moisture content.

Early in the program two calibration drums were set up containing tailings at known moisture contents, and data collected from these and initial cores from Site B showed good correlation between gauge readings and both density and moisture content. However as the program progressed, readings using the gauge were hampered by deterioration of both the mechanical condition of the probe and the gauge electronics as well as distortion of the access pipes under freezing conditions. These later readings from the gauge when compared with moistures and densities determined from corresponding core samples considerably worsened the calibration, and are regarded as suspect.

Additional information provided by the Thermogravimetric Analysis, together with the complex tailings composition has thrown considerable doubt



on the validity of standard methods for determining the moisture content of the Key Lake tailings.

The moisture density gauge calibration curves are shown on Figures B1 and B2 in Appendix B. These curves must be regarded as unreliable until operation of the gauge has been rectified and procedures for determining moisture content validated.

A summary of in-situ densities and moisture contents measured during the program is given on Table 5.2. Additional field data on core samples and corresponding moisture density gauge readings is included in Appendix B as Table B25 to B36.

In general, measured dry densities of the tailings were in the range of 0.39 to 0.63 t/m³, with corresponding solids contents of 32% and 45% respectively. Average values of dry density were 0.45 t/m³ for Site A and 0.62 t/m³ for Site B. Further observations are summarized below:

- Considerable variations in measured density and moisture content exist both laterally and vertically within the tailings.
- No measurable moisture reduction was observed at Site A after November 22nd.
- As shown from core samples taken in February and March 1985, tailings closer to the surface were generally drier and denser than those at depth, suggesting significant consolidation under suction pressures and water demands of ice formation at the surface.

It should be noted that density results obtained from the study are representative of initial layers deposited under non-typical conditions at the monitoring sites only and do not reflect average annual conditions.



TABLE 5.2

KEY LAKE PROJECT
MONITORING OF LAYERED URANIUM TAILINGS - PHASE I

SUMMARY OF DENSITY AND MOISTURE CONTENT VALUES

SITE A

<u>DATE</u>	<u>DATA TYPE</u>		<u>MOISTURE CONTENT (%)</u>	<u>SOLIDS (%)</u>	<u>DRY DENSITY (t/m³)</u>
Nov 22	cores (U of S)	Av	162.5	38.3	0.50
		Hi	186.4	41.7	0.45
		Lo	139.8	34.9	0.45
Nov 22	M.D. probe*		174.4	36.4	0.46
Jan 8	M.D. probe*		119.0	45.7	0.66
Jan 11	core		182.9	35.3	0.45
Feb 11	M.D. probe*		125.1	44.4	0.59
Feb 11	cores	Av	205.8	32.8	0.41
		Hi	216.7	35.6	0.46
		Lo	180.9	31.6	0.39
Mar 8	M.D. probe*		108	48.0	0.62
Mar 9	cores	Av	162.2	38.1	0.50
		Hi	195.8	45.2	0.63
		Lo	121.0	34.3	0.43

SITE B

Oct 17	core	124.7	44.5	0.62
Oct 17	M.D. probe*	129.4	43.6	0.64
Jan 10	M.D. probe*	129	43.7	0.59

Notes: Core data is the most reliable. Solids content and dry density may be low due to unquantified losses of combined moisture at temperatures below the 105°C drying temperature.

* Moisture Density probe data is suspect due to electronics problems associated with the instrument.

Further work on field measurements with more extensive location selection is contemplated for future work.

5.7 RADIATION MEASUREMENTS

5.7.1 Gamma Radiation

A summary of the gamma radiation measurements made at the Key Lake facility as part of this project is presented on Table 5.3. The measured levels (at a height of approximately 1 m above the monitored surface) ranged from 1.4 to 2.8 mrad/hr at Site A; 1.5 to 3.2 mrad/hr at Site B; 0.15 to 0.6 mrad/hr at the monitoring hut; and from less than 0.02 to 0.15 mrad/hr at background sites away from the tailings area.

The measured gamma levels for the two tailings sites are consistent with the theoretical levels as predicted by the basic formulae presented by Chambers et al (1980). Chambers et al. predict that for consolidated uranium tailings with a dry density of 1.6 g/cc (t/m^3) the approximate contact dose rate will be 5.1 mrad/h per % U_3O_8 .

However, before this formula can be applied it must be adjusted for density and moisture content, which for the Key Lake tailings were 0.5 g/cc and 160% moisture content, respectively. These density and moisture content averages were incorporated into the formula in the following manner.

$$\begin{array}{l} \text{Contact} = \% U_3O_8 \times \text{effective} \times \text{dry density} \times 5.1 \text{ mrad/h per } \% U_3O_8 \\ \text{Dose} \qquad \qquad \qquad \text{grade} \qquad \qquad \text{correction} \\ \qquad \qquad \qquad \text{correction} \qquad \text{factor} \\ \qquad \qquad \qquad \text{for wet} \\ \qquad \qquad \qquad \text{tailings} \end{array}$$



KEY LAKE PROJECT

Note: Readings taken approximately 1 m above surface unless indicated otherwise.

$$\begin{aligned}
 &= \% \text{U}_3\text{O}_8 \times \frac{\text{wt. of solids}}{\text{wt. of solids} + \text{wt. of water}} \times \frac{\text{actual dry density}}{1.6 \text{ g/cc}} \\
 &\qquad \qquad \qquad \times 5.1 \text{ mrad/h per } \% \text{U}_3\text{O}_8 \\
 &= \% \text{U}_3\text{O}_8 \times \frac{0.5 \text{ g/cc}}{0.8 \text{ g/cc} + 0.5 \text{ g/cc}} \times \frac{0.5 \text{ g/cc}}{1.6 \text{ g/cc}} \times 5.1 \text{ mrad/hr} \\
 &= \% \text{U}_3\text{O}_8 \times 0.38 \times 0.31 \times 5.1 \text{ mrad/h} \\
 &= \% \text{U}_3\text{O}_8 \times 0.6 \text{ mrad/h per } \% \text{U}_3\text{O}_8
 \end{aligned}$$

For Site A (3.2% U_3O_8) the predicted gamma level is $3.2 \times 0.6 = 1.9$ mrad/h, and for Site B (2.7% U_3O_8) the predicted gamma level is $2.7 \times 0.6 = 1.6$ mrad/h.

Comparison of these predicted levels with the levels presented in Table 5.3 suggest a close agreement. It should be noted that as the moisture content of the tailings decreases the gamma levels will increase. This phenomenon is borne out by the higher gamma levels measured during February on the frozen surface of tails, where partial desiccation of the upper surface layers due to exposure to extremely low temperatures would have occurred.

5.7.2 Radon Exhalation

Summary of Results

Radon exhalation rates were determined using the instrumentation described in Section 3.4.2. The measured radon exhalation rates are summarized on Table 5.4. The rates range from $0.004 \text{ Bq/m}^2 \cdot \text{sec}$ ($0.1 \text{ pCi/m}^2 \cdot \text{sec}$) for a dry sandy area, to $2.1 \text{ Bq/m}^2 \cdot \text{sec}$ ($58 \text{ pCi/m}^2 \cdot \text{sec}$) for a wet area of the tailings.



TABLE 5.4
KEY LAKE PROJECT
MONITORING OF LAYERED URANIUM TAILINGS - PHASE I
SUMMARY OF RADON EXHALATION MEASUREMENTS

<u>Date</u>	<u>Test Site</u>	<u>Description of Location</u>	<u>Radon Flux Bq/m².sec**</u>	<u>Data Correlation</u>
13/09/84	1	On tailings close to Site A, very wet tails	0.88(24)	0.98
13/09/84	1	Same as above (relocated)	0.78(21)	0.98
13/09/84	2	On dry tails, 3 m below below sprays bars (south side)	1.11(30)	0.88
14/09/84	3	Sandy dry borrow area	0.004(0.1)	0.26
15/09/84	4	On tails, 3 m below spray bars (north side)	2.15(58)	0.99
20/11/84	A	On surface of ice (150 mm thick) above tailings	0.007(0.18)	0.98
22/11/84	A	Same as above (relocated)	0.14(3.9)	0.94
13/02/85	A	On frozen tailings (350 mm thick)	*	
14/02/85	B	On frozen tailings (1200 mm thick)	*	
14/02/85	A	On surface of snow (53 cm deep)	0.026(0.69)	0.21
15/02/85	A	On surface of snow (55 cm deep)	0.03(0.90)	0.27
8/03/85	6	Till Bench in Tailings	*	
9/03/85	A	On frozen tailings (355 mm thick)	*	
10/03/85	B	On frozen tailings (1000 mm thick)	*	

Note

* - indicates that calculation of flux rate not possible, see text for discussion of "puff" theory.

** - bracketed numbers are pCi/m². sec.

The rates measured on the surface of the non-frozen tailings agree with the $1.1 \text{ Bq/m}^2 \cdot \text{sec}$ ($30 \text{ pCi/m}^2 \cdot \text{sec}$) flux rate predicted by the CEA, in Appendix XI (Radiological Report) of the EIS, for totally saturated tailings.

Discussion of Methodology

Radon exhalation rates from the surface of tailings were determined using an accumulation technique whereby the change in radon concentration within the accumulating device (in contact with the emanating surface) was measured over various time intervals. Table B37 presents a summary of the data collected during the exhalation tests.

For these tests three radon integrating detectors were used to measure the radon concentration within the accumulator. The use of three detectors maximized data recovery by providing an identification mechanism for spuriously registered radon levels. The 692 pCi/L result for unit 11, on September 13, 1984 at Site #1 recorded during the first sampling interval is an example of a spurious reading when compared with the radon levels of 5.5 and 7.1 Bq/L registered by the other two units.

The use of three monitors also assisted in the interpretation of data by providing a "triple check" on the radon levels. This triple check factor was important in the development of the "puff" theory discussed later in this section.

Data Interpretation and Discussion of Theory

Because the alphaMETER-400 radon monitor is an integrating device, the concentration measured by the unit represents the average radon



level during the sampling interval. The concentration as a function of time may be represented by:

$$C(t) = \frac{FA}{V}t + C_0 \quad (1)$$

where

- F = flux rate of radon from emanating surface (Bq or pCi/m², sec)
A = area of accumulator in contact with emanating surface (m²)
V = volume of accumulator (m³)
C₀ = initial concentration of radon in the accumulator (for this investigation assumed to be equal to 0 Bq or pCi/L.

Equation 1 may be rewritten as

$$C(t) = \frac{F}{h}t \quad (2)$$

where

- h = the height of the accumulator (m)

Figure 5.9, a graphic presentation of Equation 1, shows the average concentration $\bar{C}$ to be equal to:

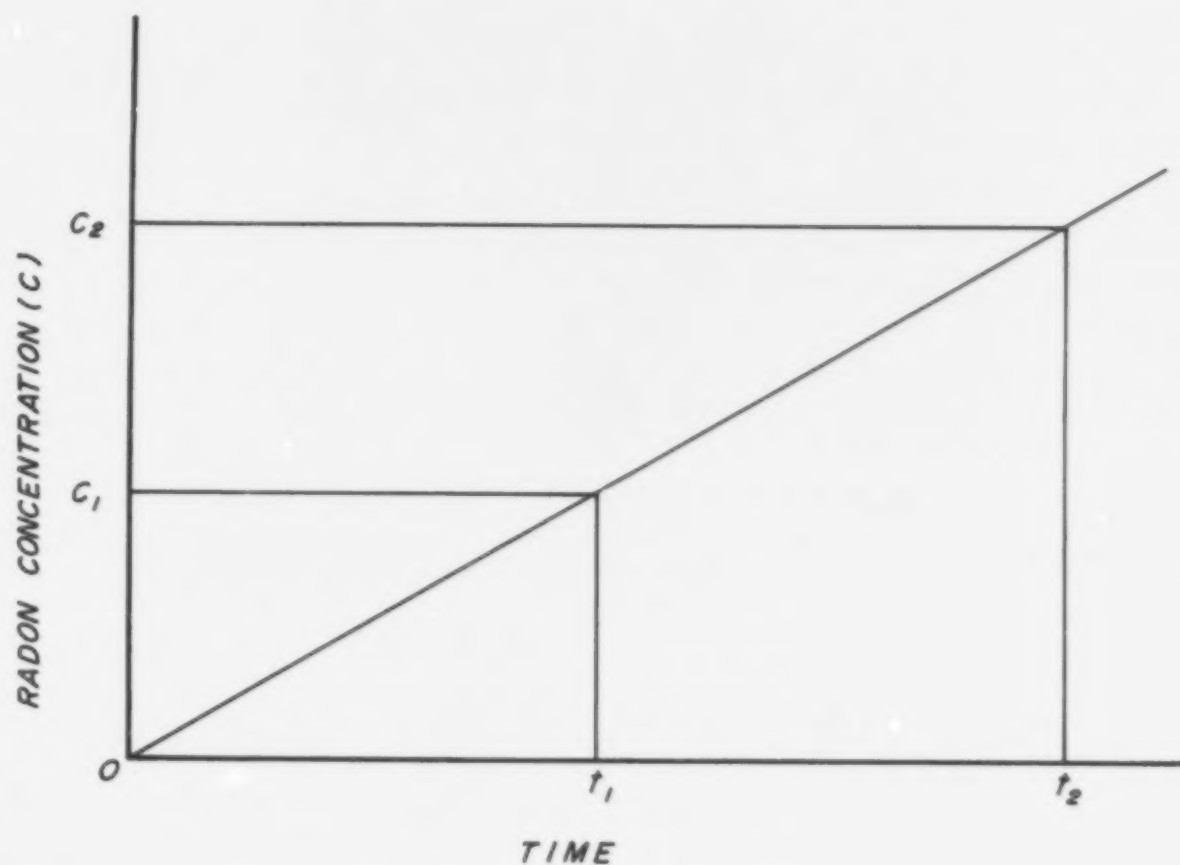
$$\bar{C} = \frac{C(t_1) + C(t_2)}{2} \quad (3)$$

incorporating equation 2 into 3



MONITORING OF LAYERED URANIUM TAILINGS - PHASE I

RADON CONCENTRATION IN ACCUMULATOR VS. TIME



$$\bar{C} = \frac{F}{2h} (t_1 + t_2)$$

Therefore by plotting the average radon concentrations measured by the monitors versus $(t_1 + t_2)$, the slope of the resulting line will be equal to $F/2h$.

Sample Calculation

For September 15, 1984 at Site #4 the radon flux rate was calculated in the following manner.

The measurements recorded by the 3 alpha METER were as follows:

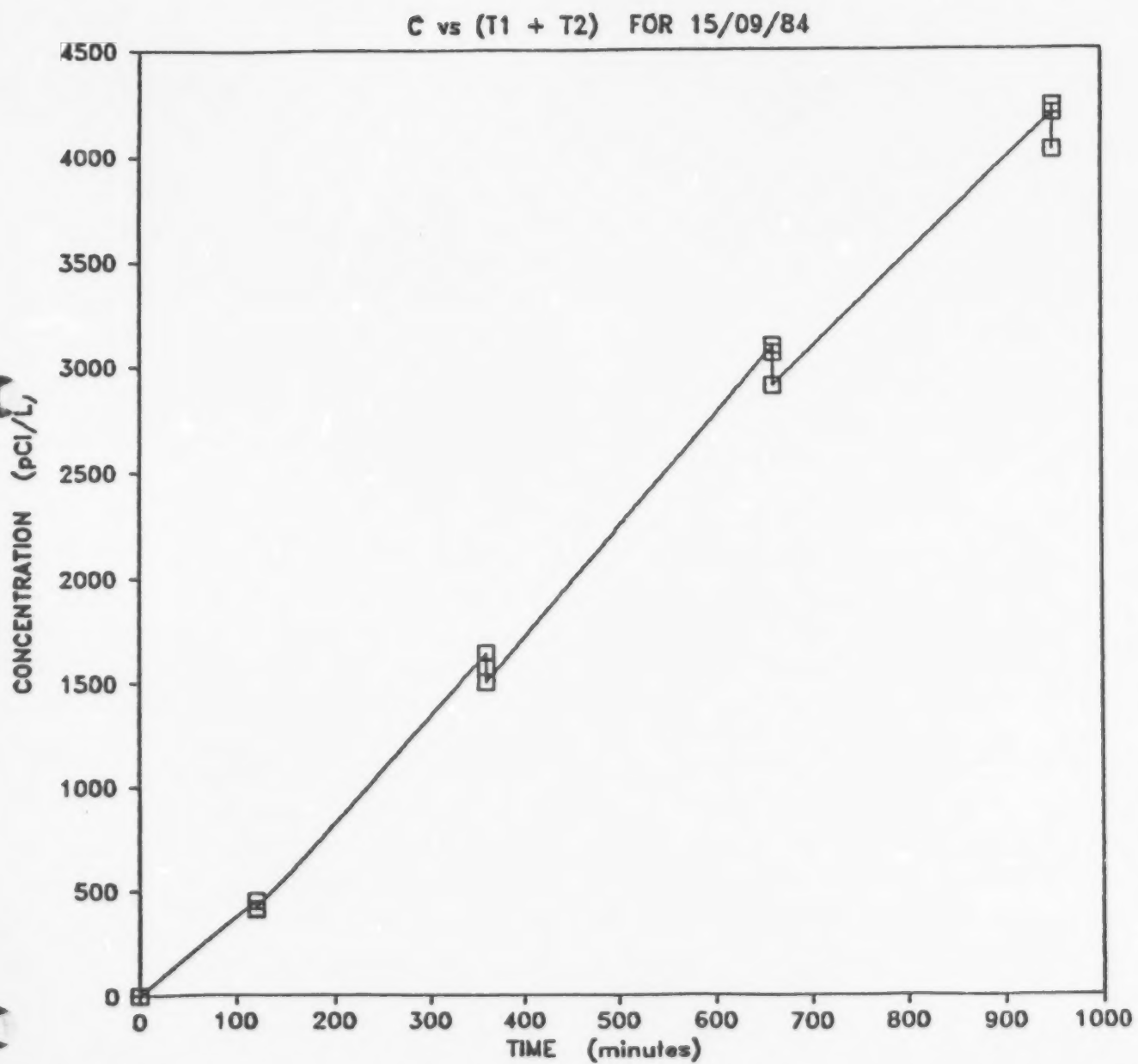
t_1	t_2	$(t_1 + t_2)$ min	Radon Concentration ($\bar{C}$) Bq/L (pCi/L)
0	120	120	16.7(450)
0	120	120	15.2(411)
0	120	120	15.4(416)
120	240	360	60.9(1645)
120	240	360	58.4(1578)
120	240	360	55.7(1505)
240	420	660	114.7(3076)
240	420	660	113.4(3061)
240	420	660	107.7(2909)
420	530	950	155.3(4194)
420	530	950	156.7(4230)
420	530	950	149.0(4022)

Figure 5.10 is a plot of $\bar{C}$ vs. $t_1 + t_2$. In order to force the line through the origin three values of $C_0 = 200$ were included in the data



KEY LAKE PROJECT
MONITORING OF LAYERED URANIUM TAILINGS - PHASE I

RADON CONCENTRATION WITH TIME (15-09-84)



KNIGHT AND PIESOLD LTD.
CONSULTING ENGINEERS

FIGURE 5.10

set to represent the initial concentrations of the three detectors.
The data listed above are best represented by the linear equation.

$$\bar{C} = 0.166 (t_1 + t_2)$$

which has a data correlation factor of 0.998.

Based on the slope of this line (equal to 0.166 Bq/L. min) the radon flux was calculated in the following manner:

$$\frac{F}{2h} = 0.166 \text{ Bq/L. min}$$

for $h = 0.39 \text{ m}$

$$F = 2 (0.39 \text{ m}) (0.166 \text{ Bq/L.min})$$

$$= 2.16 \text{ Bq/m}^2 \cdot \text{sec}$$

Discussion of Results

The radon exhalation (flux) rates, for the non-frozen tailings presented on Table 5.4 agree well with the rate predicted by the CEA, in Appendix XI of the EIS, for totally saturated tailings. The CEA predicted that based on their tests to simulate the conditions which would exist during operations the flux could vary from 1.11 to 25.9 Bq/m². sec (30 to 700 pCi/m². sec) depending on the state of the tailings surface. If the surface is kept wet the flux would be in the order of 1.11 Bq/m². sec (30 pCi/m². sec) whereas if the surface were to become dry the flux would rise to 9.3 Bq/m². sec (250 pCi/m². sec). The development of extensive surface cracking would cause the flux rate to rise to 25.9 Bq/m². sec (700 pCi/m². sec).



The condition of the tailings, during the tests carried out as part of this study, would best be described as saturated and in this regard the results obtained agree well with the CEA predictions. It should be noted however, that as the surface of the tailing becomes drier the flux rate will rise.

A marked difference in the flux rates was noted between the sandy dry area ($0.004 \text{ Bq/m}^2 \cdot \text{sec}$); the surface of the ice above Site A (0.007 to $0.144 \text{ Bq/m}^2 \cdot \text{sec}$); the surface of the snow above Site A (0.026 to $0.033 \text{ Bq/m}^2 \cdot \text{sec}$); and the tailings at Sites A and B (0.78 to $2.16 \text{ Bq/m}^2 \cdot \text{sec}$).

The measured levels of radon in the accumulator placed on the tailings during the winter months, presented in Table B37 (C) and (D), were inconsistent as compared with those made during the fall months.

Initial inspection of the data indicates possible instrument failure, however the close agreement between the data recorded by the three instruments contradicts this initial indication.

An explanation of this decrease in radon levels with time can be explained in the following manner, hereby referred to as the "puff" theory.

During the winter months the thick layer of snow on the tailings acts somewhat like a blanket and insulates the tailings surface from exposure to the very cold air.

For the radon flux measurements made in February and March this insulating blanket of snow was removed to allow the accumulator to sit directly on the surface of the tailings. However the effect of the



removal of the snow was two-fold. Initially the radon was rapidly released from evaporating moisture near the surface followed by a reduction in the radon exhalation rate to one more representative of an exposed ice covered tailings.

5.7.3 Subsequent Radon Measurements

Table B38 in Appendix B presents the results of the subsequent radon measurements made using the Track-Etch detectors. Initial inspection of the data suggests little consistency amongst the data, however closer inspection reveals the following points:

- (i) Radon levels in the upper layers of snow covering the tails are considerably less than the levels directly above the tails.
- (ii) A layer of ice on the surface of the tails greatly reduced the radon concentration above the tailings (reference to units 49,61).
- (iii) The radon concentration in close contact with the tails is not uniform over the surface of the tails (reference to units 46, 64, 65 and 49,61).
- (iv) Radon level in the monitoring hut was measured high (reference unit 50). This reading is rejected as being anomalous.

5.8 GEOTECHNICAL PARAMETERS

5.8.1 General

Two undisturbed core samples were extracted from Site A on November 22, 1984 at the locations shown on Figure 3.5. The



following tests were carried out on the samples by the Civil Engineering Department of the University of Saskatchewan to determine relevant material parameters:

- Specific gravity
- Particle size distribution
- One dimensional consolidation tests
- Saturated permeability tests
- Unsaturated permeability tests
- Settling and air-drying tests

This section gives a summary of the geotechnical test results and comments on material parameters.

5.8.2 Specific Gravity

Two tests for specific gravity were carried out on material from each core sample with results as follows:

<u>SAMPLE</u>	<u>TEST</u>	<u>SPECIFIC GRAVITY</u>
A1	1	2.90
	2	2.93
A2	1	2.99
	2	2.94

These values do not correspond to all previous tests carried out on the Key Lake tailings, for which an average value of 2.64 has been obtained. The apparent discrepancy is attributed to difficulty in carrying out a standard pycnometer test with these tailings. For all calculations, a value of 2.64 has been used.



UNIVERSITY OF SASKATCHEWAN
SOIL MECHANICS LABORATORY

GRAIN SIZE CURVE

PROJECT Uranium Tailings

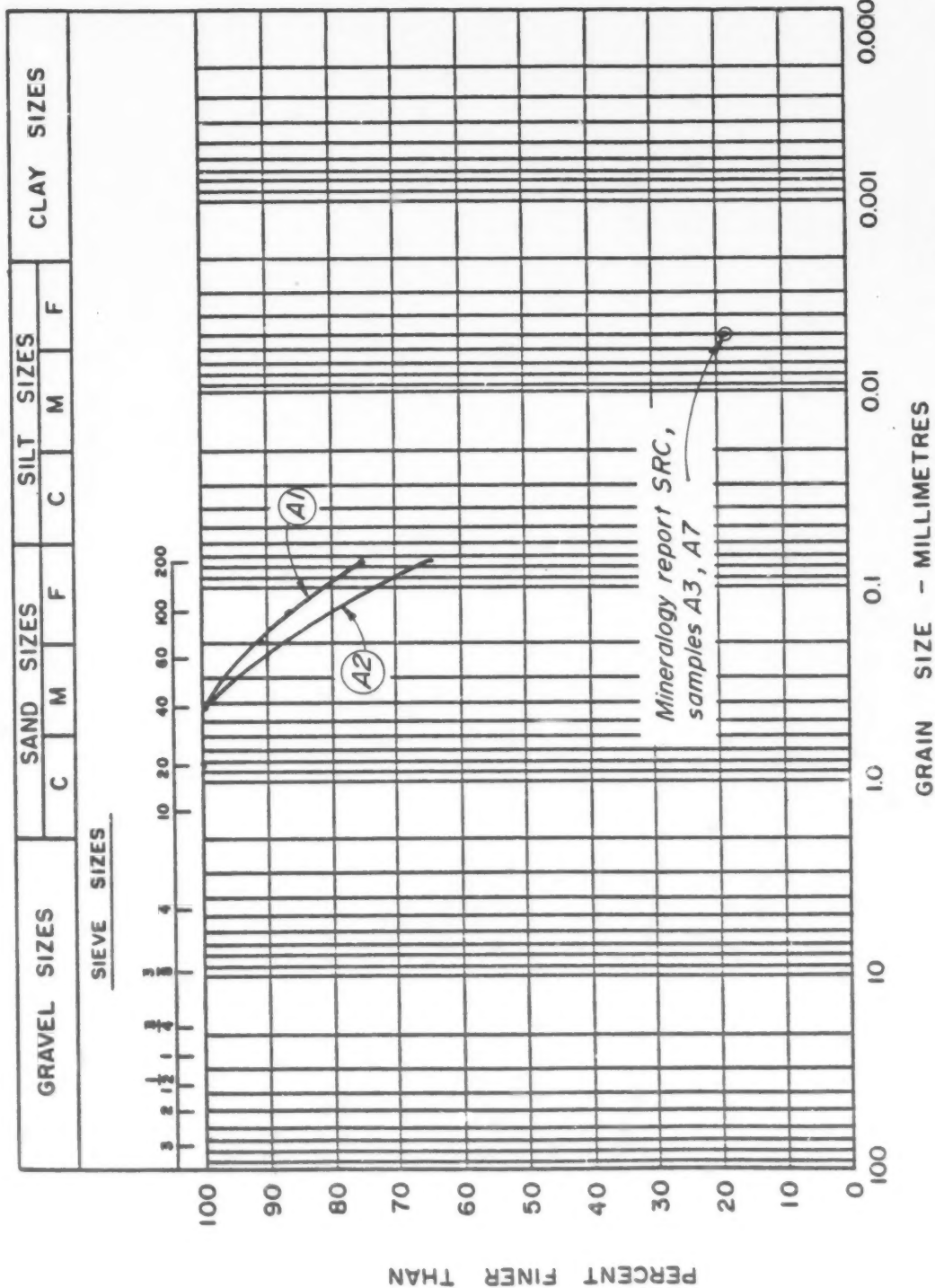
LAB. ORDER

SAMPLE A1, A2

LOCATION Key Lake

HOLE DEPTH

TECHNICIAN DATE



D_{10} =
 D_{60} =
 C_u =

REMARKS

5.8.3 Particle Size Distribution

Particle size distribution tests carried out on each core sample passing were limited to sieving the material through a set of nested sieves between the #40 and #200 sizes. Hydrometer tests were not completed on the minus 200 sieve fraction due to the inability of dispersing agents normally used for soil testing to influence this material, resulting in extremely rapid settling of agglomerated silt and clay size particles. For chemical/mineral tailings of this type some additional work is necessary to establish a method for quantifying silt and clay size particles. Results of the sieve analyses are shown on Figure 5.15.

An additional point on the size distribution curves is provided by the mineralogy study carried out at SRC. This indicated approximately 18 percent by weight finer than 5 microns. This test was carried out on a different sample of tailings but can be considered to be representative of the material in the vicinity of Site A.

Both samples can be classified as sandy silt materials with 100 percent of particles finer than 0.4 mm. The material tested from sample A1 was slightly finer than the material tested from sample A2.

5.8.4 Density Results

Dry density and moisture content values for the core samples were determined on material extracted from 3 horizons within each core. These values have been reported in Section 5.6. The measured dry densities varied between 0.45 t/m^3 and 0.58 t/m^3 (35.3 and 41.7 percent solids).



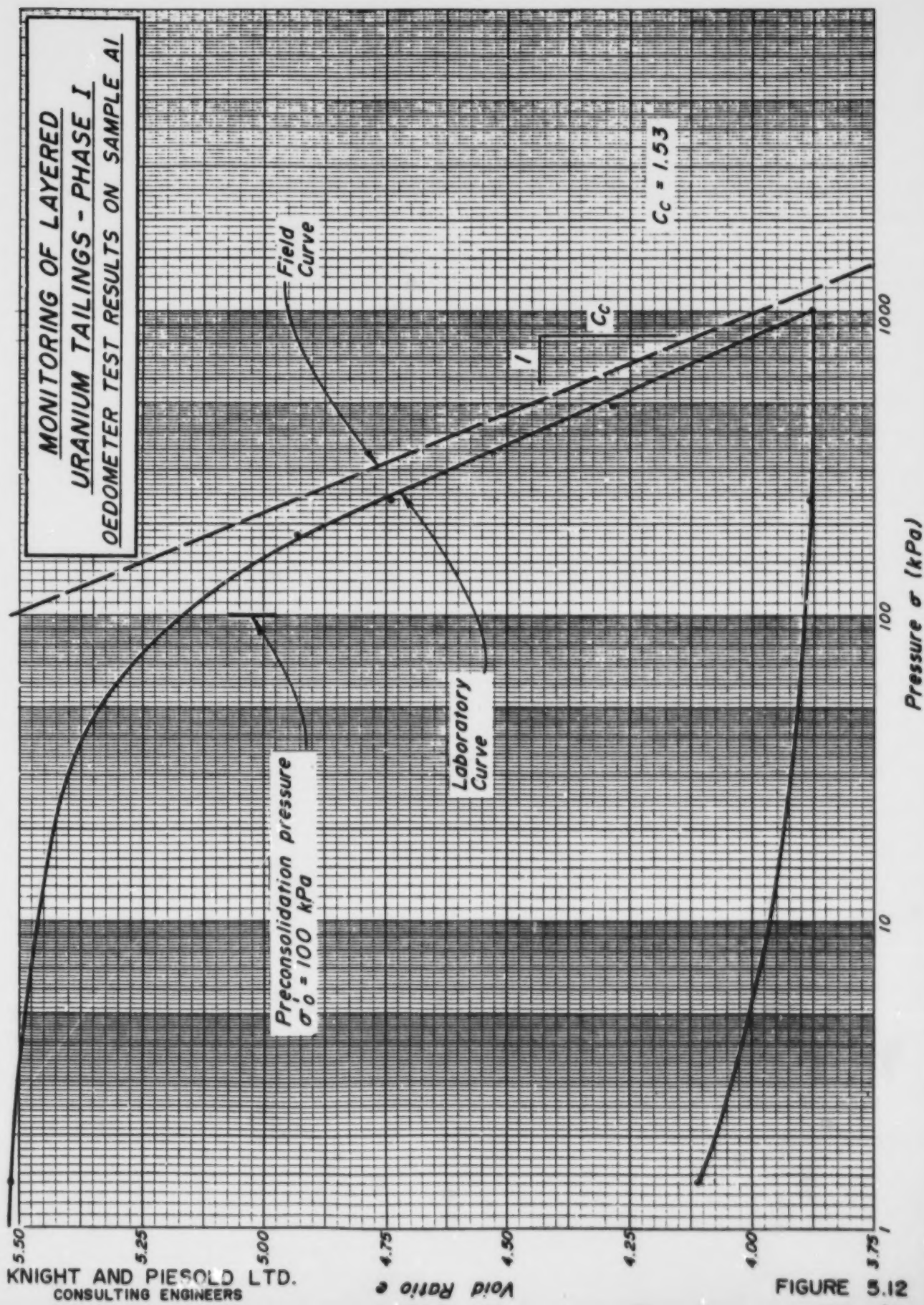


FIGURE 3.12

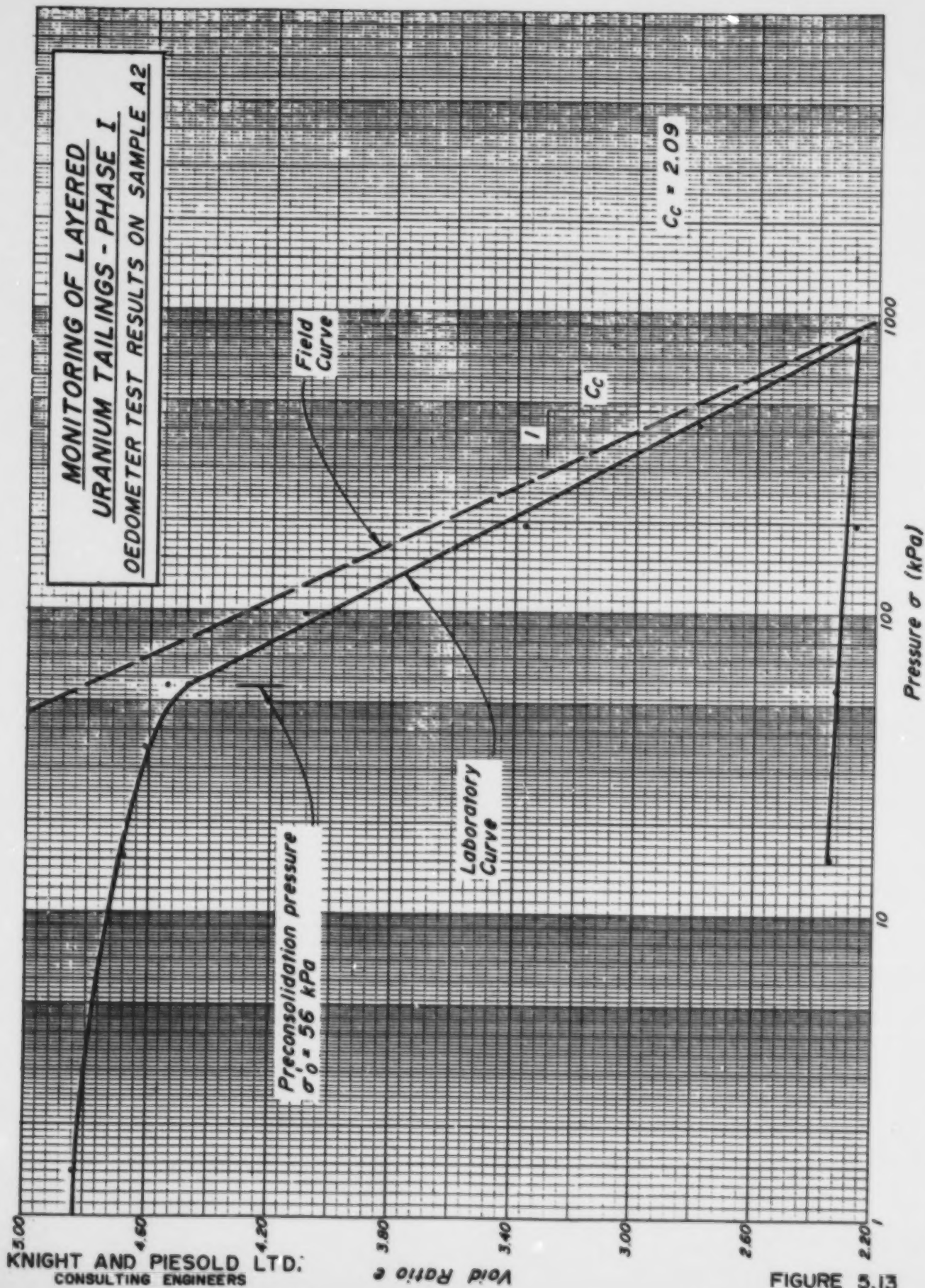


FIGURE 5.13

The variable nature of the dry density and moisture content values corresponding to different portions of each core sample is probably due to partial segregation of the material resulting in discrete layers with slightly different physical characteristics.

5.8.5 Consolidation Test Results

Oedometer tests were carried out on an undisturbed sample of material from each core to determine the consolidation and compressibility characteristics of the tailings. The results of these tests are shown as plots of void ratio versus effective stress on Figures 5.12 and 5.13 for samples A1 and A2 respectively. For both tests the field curve for virgin consolidation of the material has been derived which corresponds to normal consolidation of the tailings in the field. The consolidation and compressibility parameters, c_v and m_v , together with the calculated values for coefficient of permeability for the larger loading increments applied to each sample are tabulated on Table 5.5.

The consolidation test results show that sample A2 was consistently more compressible than A1 but the rate of consolidation of sample A1 was greater than A2 at large stress levels. The values for the coefficients of permeability calculated from the tests ranged between 1×10^{-8} and 1×10^{-9} m/s and followed a decreasing trend as the samples were progressively consolidated under higher effective stresses.

Measured values of the coefficient of consolidation, c_v , varied between 15 and 102 m^2/yr . These values are slightly higher than values measured in previous testing on the Key Lake tailings, and on other high grade uranium tailings, which were in the range of 5 m^2/yr at low effective stress levels to 30 m^2/yr above 50 kPa. The



TABLE 5.5

KEY LAKE PROJECT

MONITORING OF LAYERED URANIUM TAILINGS - PHASE I

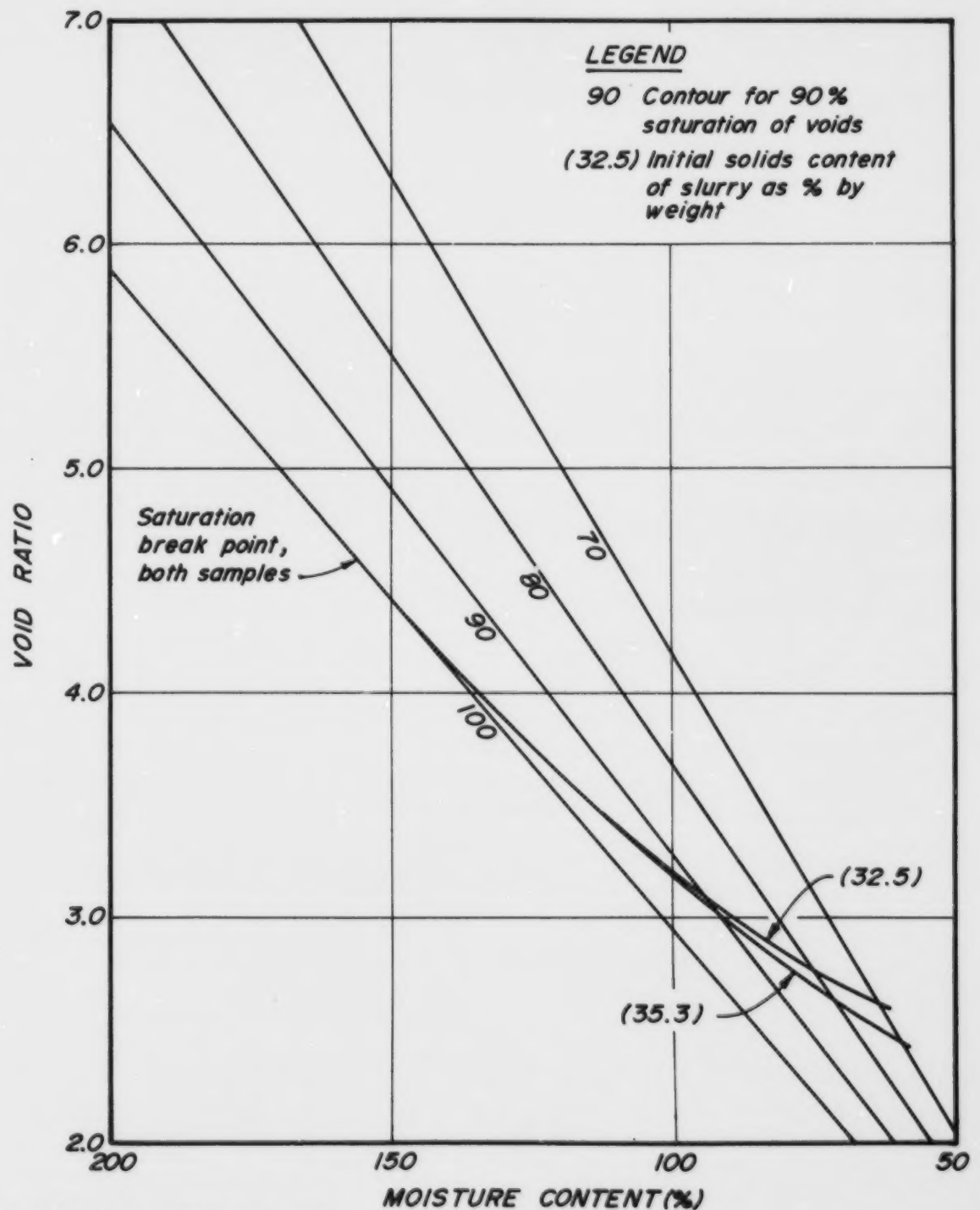
OEDOMETER TEST RESULTS

CONSOLIDATION AND COMPRESSIBILITY PARAMETERS

SAMPLE	STRESS RANGE (kPa)	c_v (m^2/yr)	m_v (m^2/kN)	CALCULATED k (m/s)
A1	240			
		52.73	.00031	5×10^{-9}
	495			
		102.00	.00015	4×10^{-9}
	1017			
A2	56			
		37.70	.00194	2.2×10^{-8}
	98.5			
		64.91	.00143	2.8×10^{-8}
	197			
		41.25	.00059	7×10^{-9}
	422			
		15.47	.00034	1×10^{-9}
	816			

c_v = coefficient of consolidation
 m_v = coefficient of compressibility
 k = coefficient of permeability

MONITORING OF LAYERED URANIUM TAILINGS - PHASE I
RESULTS OF SETTLING AND AIR DRYING TESTS ON TAILINGS



implications of this are that the tailings will consolidate more quickly under increased loading.

5.8.6 Settling and Air-Drying Tests

Settling and air-drying tests were carried out on laboratory samples of the tailings to investigate the relationship between moisture content, void ratio and saturation with the specific objective of determining the void ratio at the on-set of partial saturation. This void ratio was subsequently used as the starting point for unsaturated permeability testing.

A total of four samples were tested at initial solids contents of 22.8, 28.8, 32.5 and 35.3 percent by weight. The results of the last two tests are plotted on Figure 5.14. The results show the void ratio at the saturation break point to be approximately 4.5. This corresponds to a dry density of 0.48 t/m^3 and correlates well with measured densities at Site A.

In conjunction with the settling and air-drying tests identical containers of water were set up to correlate water loss by evaporation from the tailings surface with that from a free water surface. The evaporation rates were found to be similar over the entire range of moisture contents tested, with no reduction in evaporation observed for the tailings samples when unsaturated, as might be expected. The implications of this with regard to the seepage modelling are discussed in Section 10.0.

5.8.7 Saturated Permeability Tests

Constant head permeability tests were carried out on two samples of tailings slurried to a solids content of 35 percent and settled and pre-consolidated to a void ratio of 4.5. Each sample was tested under



hydraulic gradients of 50 and 100 in a permeameter to determine the coefficient of permeability in the saturated state. The results are as follows:

<u>SAMPLE</u>	<u>GRADIENT</u>	<u>k (m/s)</u>
1	50	1.24×10^{-7}
	100	1.38×10^{-7}
2	50	1.11×10^{-7}
	100	1.24×10^{-7}

The results show that the saturated coefficient of permeability remained constant over the range of gradients tested for both samples. In addition, these results showed that the samples tested under low effective stresses in the permeameter were up to 25 times more permeable than the samples tested in the oedometer apparatus. This is attributed to the increased effective stress and resulting consolidation of the samples in the oedometer test.

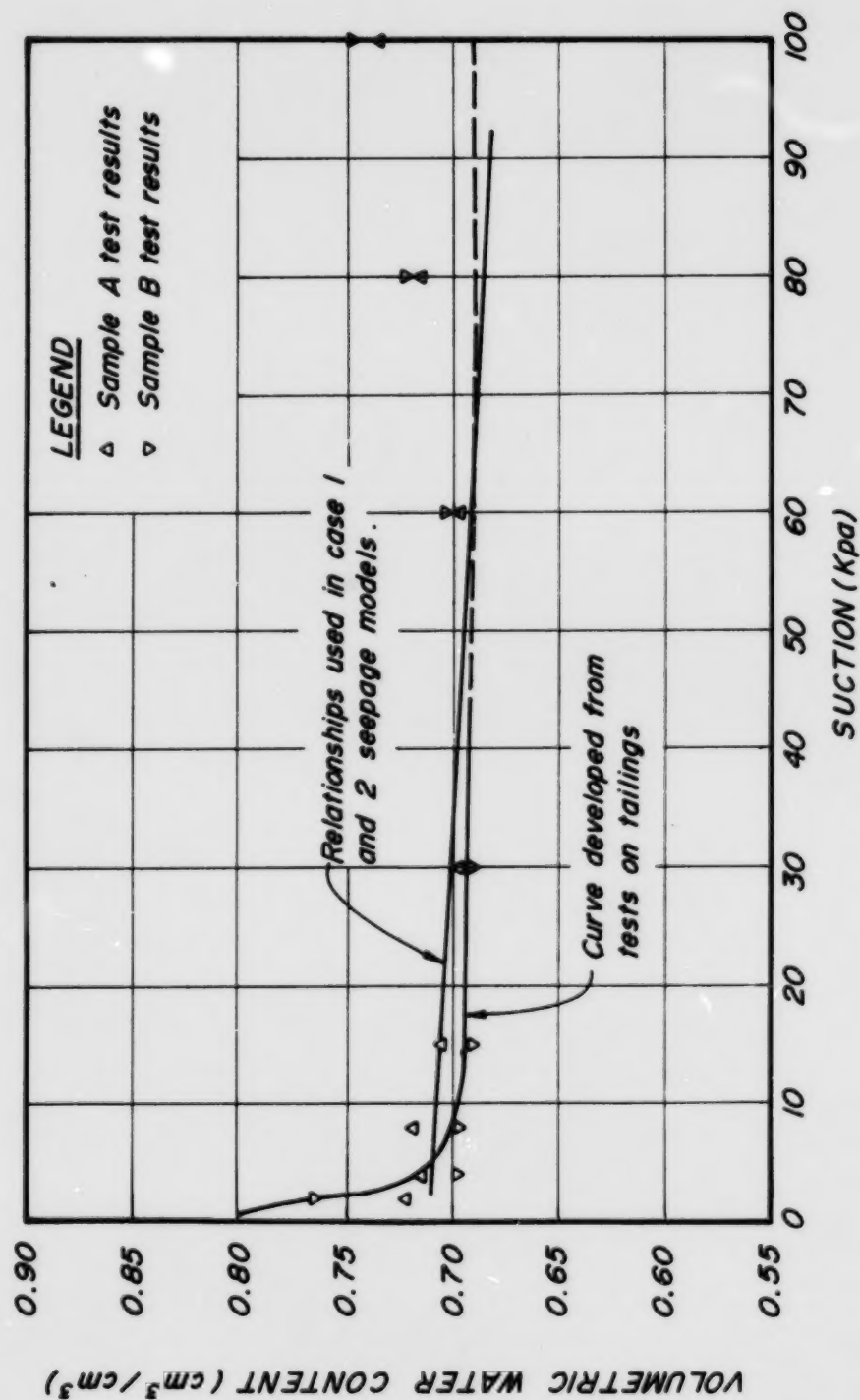
5.8.8 Unsaturated Permeability

Two samples of tailings were tested to determine the coefficient of permeability of the material under partially saturated conditions. The samples were initially prepared to a void ratio of 4.5 in the same manner as the samples tested for saturated permeability. Each test involved mounting a fully saturated sample in a "Tempe Cell" apparatus and applying progressively greater suction pressures to desaturate the samples. The test provides a relationship between volumetric water content and suction pressure for the samples which, together with the saturated permeability, is used to develop the relationship between suction pressure and unsaturated permeability



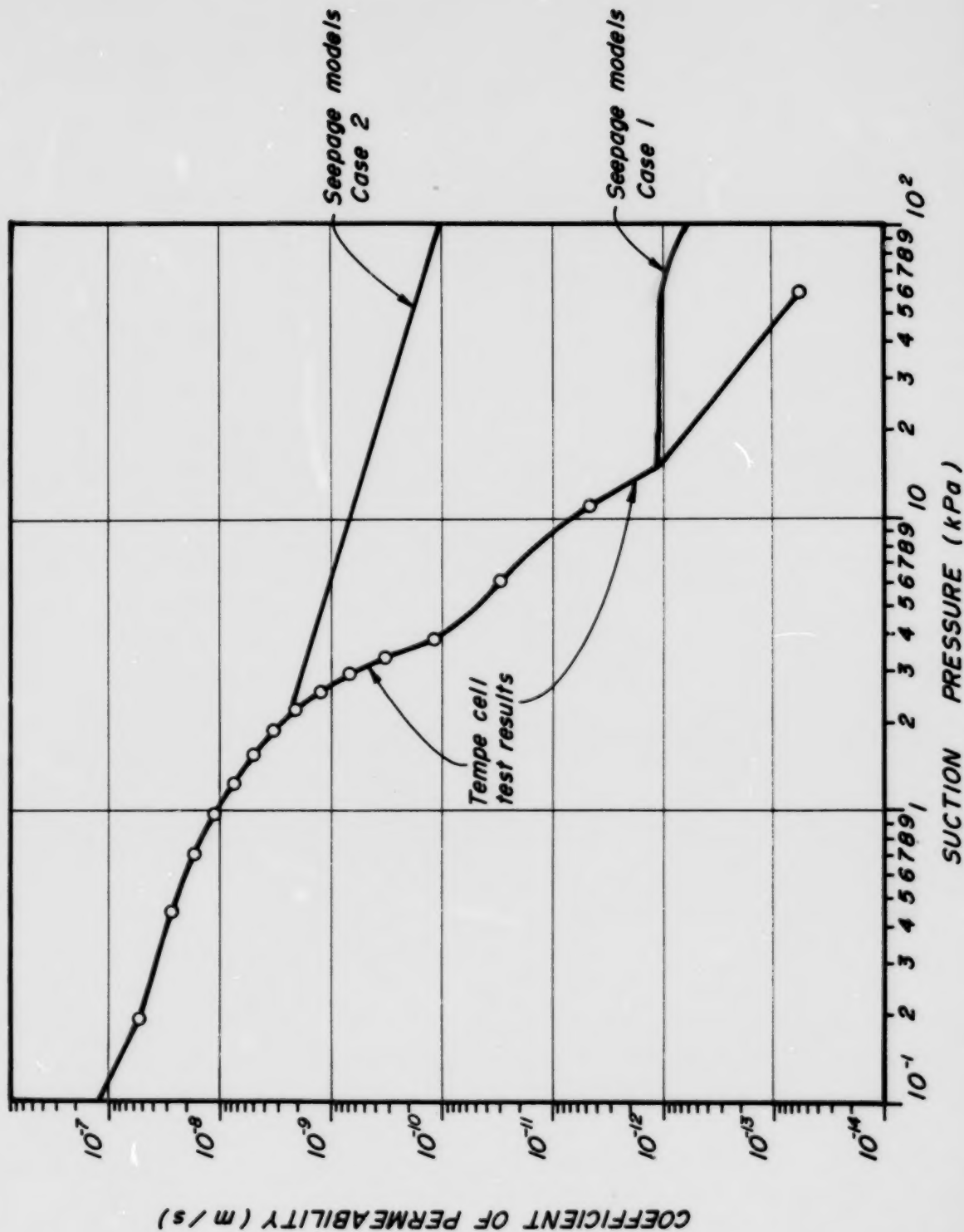
MONITORING OF LAYERED URANIUM TAILINGS - PHASE I

FUNCTION RELATING VOLUMETRIC WATER CONTENT AND
NEGATIVE PORE WATER PRESSURE FOR KEY LAKE TAILINGS



MONITORING OF LAYERED URANIUM TAILINGS - PHASE I

**FUNCTIONS RELATING COEFFICIENT OF PERMEABILITY AND
NEGATIVE PORE WATER PRESSURE FOR KEY LAKE TAILINGS**



using an empirical formula. The method is well established and widely accepted.

Results of both tests were very similar and the relationships between volumetric water content and suction pressure are shown on Figure 5.15. The function relating coefficient of permeability to suction pressure is given on Figure 5.16. The functions used in the seepage models discussed in Section 10.0 are also shown on the latter Figure.

The tests indicate that a very significant decrease in permeability occurs once suction pressures are developed and the material becomes unsaturated. For example, a suction pressure of 1 kPa (100 mm water) will reduce the coefficient of permeability by one order of magnitude, and a suction pressure of 10 kPa (1 m water) will reduce it by over four orders of magnitude, to less than 10^{-11} m/s.



SECTION 6.0 - OBSERVED TAILINGS BEHAVIOUR

6.1 TAILINGS DEPOSITION

Observations and measurements of various data have been made at Site A for deposition of approximately 2 metres of tailings and subsequent drainage and consolidation. Although detailed observation was limited to the period from September 1984 to March 1985, explanations of observed behaviour have been attempted.

The full depth of tailings at Site A was deposited from mid-July to mid-October, a period of approximately 13 weeks. This represents an average rate of build-up of 0.15 metres per week, or 8.0 metres per year. As such little consolidation would have been expected during this period, and continuous infiltration at relatively high seepage rates would have occurred into the underdrain. The surface of the tailings became frozen shortly after deposition ceased.

This rapid build-up has resulted from confinement of the tailings within the relatively small area of the temporary tailings impoundment. The average build-up of tailings over the entire surface area of the facility will be approximately 2 metres per year.

Positive pore pressures were observed within the tailings at commissioning of the pore pressure transducers in October, 1984 and a positive hydrostatic pressure was observed in the underdrain on installation of the standpipe piezometers on November 22, 1984. Details are presented in Section 5.2. From November onwards a steady fall in the water table in the underdrain was observed with drainage complete by January 7, 1985. Throughout this period relatively large seepage flows were recorded, as presented in Section 5.4. No further seepage was collected after drainage was complete.



Knight and Piessold Ltd.

CONSULTING ENGINEERS

A continuing decline in pore pressures was observed within the tailings for the remainder of the monitoring period, with suction pressures developing over the full tailings depth. These suction pressures would have served to consolidate the tailings and, although little change in density was observed over-time, a definite tendency for increasing density with height above the filter blanket was established from core samples taken in January, February and March (Section 5.6).

Some simplistic analyses are discussed in the following sub-section to demonstrate the observed tailings performance.

6.2 CONSOLIDATION AND DRAINAGE

An analysis developed by Gibson (1958) relating the degree of consolidation, U , to the rate of rise of the soil or tailings, m , can be used to investigate the initial deposition phase. Using $m=8.0$ m/yr for a duration $t=0.25$ yrs the following results are obtained, assuming unrestricted two-way drainage:

$\frac{c_v}{(m^2/yr)}$	$\frac{m^2 t}{c_v}$	U	Maximum Pore Pressure (mm H ₂ O)
5	3.20	0.7	520
30	0.53	0.9	200

This indicates that some consolidation would have occurred on an on-going basis during deposition, but that residual pore pressures could be anticipated at the end of deposition. However, the above analysis assumes unrestricted bottom drainage, whereas a positive hydrostatic head was observed in the underdrain after deposition ceased.



Association
of Consulting
Engineers
of Canada

Association
des Ingénieurs-
Conseils
du Canada

Figure 2.1 shows the location of Site A approximately midway between drainage pipes within the filter blanket on the base of the facility. Average grades on the underseal in this area are approximately 1 percent.

During deposition of the initial layers, relatively high infiltration into the filter blanket occurs at a rate considerably in excess of subsequent seepage from the base of the tailings. The high initial infiltration rate will cause a temporary mounding of the phreatic surface in the filter blanket with a peak at the mid-point between drainage pipes.

Using the Dupuit equation and an infiltration rate equal to the saturated permeability of the tailings, the maximum build-up of hydrostatic head, h , in the filter blanket can be estimated from:

$$h^2 = \frac{e l^2}{4k}$$

- where e = infiltration rate = 1.2×10^{-7} m/s
 l = half the distance between drains = 50 m
 k = permeability of filter blanket = 5×10^{-5} m/s

which gives

$$h = 1.22 \text{ m}$$

The thickness of filter blanket in this area is 0.5 m and therefore a maximum hydrostatic head of 720 mm is predicted at the base of the tailings. The actual measured head in the standpipes at the base of the tailings on November 22, 1984, approximately 5 weeks after deposition ceased, was 500 mm. The implication of this build-up of hydrostatic head in the underdrain is that restricted vertical drainage would result in higher

Knight and Piésold Ltd.

CONSULTING ENGINEERS

residual pore pressures within the tailings than those predicted in the previous analysis for the end of deposition.

Throughout the period when seepage flows were being collected at Site A, operation of the sump pump was draining down the phreatic surface within the liner beneath the monitoring site on each pumping cycle. This would have resulted in a large head differential between the filter blanket under the monitoring site and the adjacent overall filter blanket. Large gradients would therefore have existed around the perimeter of the monitoring site liner and the resulting inflow from outside the monitoring site is considered to be the major contributor to measured seepage flows approximately 5 times the anticipated flow under unit hydraulic gradient.

On-going consolidation after deposition ceased is controlled by the surface and filter blanket boundary conditions. Surface freezing will create an upward movement of moisture and will serve to rapidly consolidate the upper portions of the tailings. Drainage within the filter blanket controls the lower boundary condition on the tailings, where the hydrostatic head was observed to fall from 500 mm on November 22, 1984 to zero by January 7th, 1985.

This process of consolidation can be modelled using a step-wise finite difference technique and varying the top and bottom boundary conditions with time. While various extreme simplifying assumptions must be made regarding the contribution and development of suction pressures at the frozen surface boundary, the technique indicates fairly rapid consolidation in phase with the decreasing head at the boundary conditions. In general, the analysis indicated that 90 percent consolidation occurs approximately 20 days after any change in boundary conditions, such that zero pore pressures or less would be predicted throughout the tailings by mid-January, 1985.



Association
of Consulting
Engineers
of Canada

Association
des Ingénieurs-
Conseils
du Canada

Knight and Piesold Ltd.

CONSULTING ENGINEERS

Although difficulties in measuring absolute values of pore pressures were experienced with the particular transducers selected, the predicted result is reasonably supported by the observed data. A much more rigorous analysis of on-going seepage and moisture movement within the tailings is presented in Section 10.0.

6.3 WATER BALANCE

Overall operation of the tailings facility to date has been dramatically influenced by the temporary storage of excess contaminated water from start-up. This water was finally removed in January, 1985. Deposition of tailings since start-up in late 1983 has largely been confined to the western half of the facility, with the aim of keeping tailings up slope of the ponded area. This has resulted in a rate of build-up of tailings somewhat higher than as designed. However, the monitoring study has provided useful information on the behaviour of the tailings under these initial conditions and a preliminary estimate of water balance for the facility has been attempted.

Tailings deposition from mid-July to mid-October was confined by a small retention dyke in the north west corner of the tailings facility, as shown on Drawing No. 1602.103. Observations over the deposition period allow for a rough mass balance to be undertaken for the tailings within this area.

Tailings production from the Key Lake mill for the months of July to October is summarized on Table 6.1. It has been assumed that all tailings produced from mid-July to mid-October were deposited in the confined area.

The following additional data have been used:



Association
of Consulting
Engineers
of Canada

Association
des Ingénieurs-
Conseils
du Canada

TABLE 6.1

KEY LAKE PROJECT
MONITORING OF LAYERED URANIUM TAILINGS - PHASE I

MONTHLY TAILINGS PRODUCTION - 1984

Month	Solids (tonnes)	Water (tonnes)	Volume (m ³)	Percent Solids	Percent Moisture	Moisture Content (%)	Volumetric Water Content (m ³ /m ³)
July	21,600	58,600	66,800	26.9	73.1	271	0.877
August	22,800	59,700	68,500	27.6	72.4	262	0.872
September	19,400	64,800	72,300	23.0	77	334	0.896
October	16,400	69,400	75,800	19.1	80.9	423	0.916
Totals	80,200	252,500	283,400				
Averages				24.1	75.9	315	0.890

Notes:

- (1) Data extracted from KLMC daily operating reports.
- (2) Volume = Weight of Water + Weight of Solids/2.6 (KLMC) (m³)
- (3) Moisture Content = 100 x Weight of Water/Weight of Solids. (%)
- (4) Volumetric Water Content = Weight of Water/Total Vol. (m³/m³)

Knight and Pietsold Ltd.

CONSULTING ENGINEERS

Impoundment Area	60,200	m ²
+ Assumed rainfall over period	150	mm
* Final tailings dry density	0.45	t/m ³
* Equivalent void ratio (S.G. = 2.64)	4.9	
* Final moisture content (% dry wt.)	184	%
*(January core sample)		
+(KLMC records)		

The resulting water balance is summarized below:

Input

Water

- rainfall	9,000	m ³
- water with tailings	188,500	m ³
- total water input	197,500	m ³

Solids

- total weight	61,200	t
- solids volume (S.G. = 2.64)	23,181	m ³

(Average solids content of incoming tailings = 24.5%)

Retained

Water (at m/c = 184% dry wt.)	112,600	m ³
Total volume (water + solids)	135,781	m ³
Average depth of tailings (assuming 100% saturation)	2.26	m



Association
of Consulting
Engineers
of Canada

Association
des Ingénieurs-
Conseils
du Canada

Water Output

Total water output	84,900	m ³
(drainage + runoff + evaporation)		
Percentage of total water input	43	%
Percentage of tailings water input	45	%

The above water balance is verified by field observations in terms of average depth of tailings build-up. The total water recovery as a percentage of initial water input is also generally in line with settling tests carried out on random samples of tailings flowing into the facility which are summarized below:

Initial Solids Content (%)	Final Solids Content (%)	Final Dry Density (t/m ³)	Water Recovery (% of Initial Water Volume)
16	28	0.35	52
30	40	0.53	35

It should be noted that the water balance presented above is derived from very limited information, and it is not possible to accurately proportion the water output between seepage, supernatant runoff and evaporation.

As mentioned in Section 6.2, there is strong evidence suggesting actual seepage flows from Site A are predominantly influenced by horizontal seepage into the monitoring site from the surrounding filter blanket and tailings. However, assuming seepage from the tailings at unit hydraulic gradient the total volume of water reporting to the underdrain over the impoundment area considered in the water balance is estimated as:

$$\text{Seepage} = 1.2 \times 10^{-7} \times 1 \times 60,200 \quad \text{m}^3/\text{s}$$

$$= 56,800 \text{ m}^3 \text{ (total mid-July to mid-October)}$$



Knight and Piesold Ltd.

CONSULTING ENGINEERS

On this basis the relative proportions of water output for the initial layers of tailings deposition is as follows:

Total Water Output	84,900	m ³
Seepage (% of output)	67	%
Runoff + Evaporation (% of output)	33	%

A major objective of the proposed Phase II of the monitoring study will be to further define evaporation and seepage into the underdrainage system as deposition continues over the initial tailing layers.

References

Gibson, R.E. (1958) "The progress of consolidation in a clay layer increasing in thickness with time". *Geotechnique* 8, pp 171-182.

For Dupuit assumption for unconfined flow see:

Brouwer, H. (1978) "Groundwater Hydrology". McGraw-Hill.



Association
of Consulting
Engineers
of Canada

Association
des Ingénieurs-
Conseils
du Canada

SECTION 7.0 - CHEMICAL AND MINERALOGICAL PROPERTIES - TAILINGS SOLIDS

7.1 PROGRAM OUTLINE

The tailings solids testing program was carried out on core samples discussed in Section 3.7. Experimental procedures are outlined on Figure 7.1. The primary objectives of this program were to:

- (i) Obtain data on the chemical and radiological composition.
- (ii) Obtain data on the mineralogical characteristics of the tailings (for both an understanding of the mineral composition as well as for determining geochemical mobility of elemental species).

7.2 CHEMICAL AND RADIOLOGICAL CHARACTERISTICS

The Key Lake metallurgical process includes crushing, grinding, sulphuric acid leaching for uranium dissolution, solvent extraction ammonia precipitation for uranium recovery and lime neutralization of tailings solids and barren solutions. Because of the high acid demand the neutralized tailings solids contain 20% or more by weight of CaSO_4 , most of which is derived from chemical addition in the mill.

Three core samples from Site A labelled A3, A7, A8 and three from Site B, labelled B1, B2 and B3 were analyzed for major elements, radionuclides and organic content. The measured results for the 6 core samples are provided on Table 7.1 along with the cumulated average concentrations.



TABLE 7.1

KEY LAKE PROJECT
MONITORING OF LAYERED URANIUM TAILINGS - PHASE I

ANALYSIS OF CORE SOLIDS

Analysis	Units	A3	A7	A8	B1	B2	B3	Avg.
Al	mg/g	33.3	27.8	30.3	22.8	26.6	24.5	27.6
As	mg/g	13.4	13.0	12.2	12.8	2.8	11.7	11.0
Ca	mg/g	95	79.6	92.2	60.1	65.9	39.5	72
Co	mg/g	0.49	0.54	0.52	0.73	0.72	0.69	0.62
Fe	mg/g	27.5	23.0	23.5	18.8	20.8	18.4	22
Mg	mg/g	9.7	9.5	9.2	6.9	7.5	6.6	8.2
Mo	ug/g	20	12	12	12	12	10	13
Ni	mg/g	16.1	16.7	15.9	19.8	20.4	17.5	17.7
Si	%	18.9	20.3	23.9	26.7	23.9	30.2	24
U	ug/g	473	403	471	626	543	530	508
Th-230	Bq/g	320	280	260	250	270	180	260
Ra-226	Bq/g	340	320	300	250	310	260	300
Pb-210	Bq/g	380	360	340	240	220	260	300
Po-210	Bq/g	260	290	230	200	250	230	250
SO ₄	%	18.6	16.7	17.3	12.8	15.9	10.3	15.3
CO ₃	%	5.4	4.3	5.3	3.6	2.1	1.5	3.0
Tertiary Amine	%	.01	.017	0.015	0.0072	0.0080	0.0051	.01
Isodecanol	ug/g	<10	<10	<10	<10	<10	<10	<10
Kerosene	ug/g	750	1080	2160	290	600	750	940
C.E.C.	meq/100g	2.2	5.4	-	-	-	-	

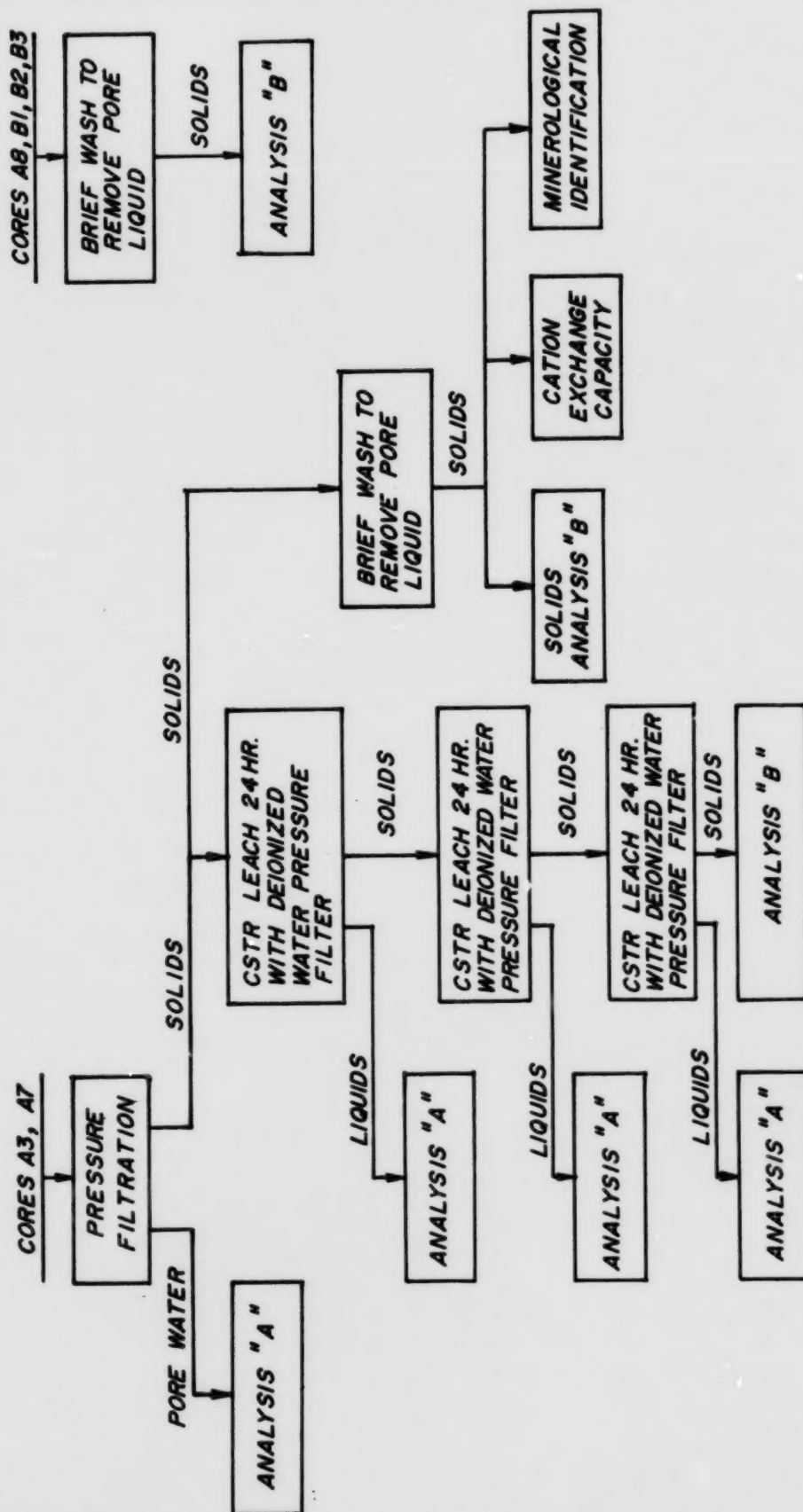
C.E.C. - Caton Exchange Capacity.

Note: Analyses for A3 and A7 were carried out after third leach.

Analyses for A8, B1, B2 and B3 were carried out after a brief initial wash.

MONITORING OF LAYERED URANIUM TAILINGS - PHASE I

WORK FLOW SHEET - CORE SAMPLES



ANALYSIS A : Includes Plasma Scan, Radionuclides, Nutrients, Organics (Kerosene, Isodecanal, Tertiary Amine), etc
 ANALYSIS B : Al, As, Ca, Co, Fe, Mg, Mo, Ni, Si, U, Th230, Ra226, Pb210, Po210, So, Co, Organics
 ANALYSIS C : pH, conductivity, Eh

Radiological Characteristics

Site A samples appear to contain a higher grade uranium tailings than Site B. Accordingly, Site A has higher calcium and sulphate content, lower silica content, and higher radioactivity levels.

The radionuclides from both sites are approximately in secular equilibrium with Th-230 and Po-210 being at slightly lower activities.

Using the average Ra-226 activities of 320 Bq/g for Site A and 273 Bq/g for Site B and considering the fact that the original mill feed has been diluted with chemical precipitates (gypsum) the average original uranium mill feed grade for the tailings in Site A and B are approximately 4.0% U_3O_8 and 3.2% U_3O_8 respectively.

The low average uranium level in the tailings at 508 ug/g would indicate that greater than 98% U_3O_8 recovery was being achieved when the tailings were placed.

The average specific activity measured for the combined sites was 260 Bq/g Th-230, 300 Bq/g Ra-226, 300 Bq/g Pb-210 and 250 Bq/g Po-210. Both Th-230 and Po-210 activities appear to be below equilibrium levels. The thorium levels may be biased on the low side by one result of 180 Bq/g which appears to be an outlier. Po-210 levels may be recorded somewhat lower than they actually are due to radiological decay during the laboratory procedures.

Chemical Characteristics

The chemical composition of the tailings is more or less as would be anticipated. Some interesting unexpected observations included:

- Low molybdenum levels averaging 13 ppm.



- High carbonate content averaging 5% as CaCO_3 (as measured by assay).
- Lower than expected aluminum content averaging 2.8 percent.
- Uranium grade that was inversely proportional to nickel and arsenic content.

Organic Content

The solvent extraction circuit employs trace organic chemicals, kerosene, tertiary amine and isodecanol. Little data is printed in the literature on the fate of these chemicals in uranium tailings areas. The average levels measured on the tailings solids was 0.094% kerosene, 0.01% tertiary amine and 10 ug/g isodecanol.

Average tailings production is approximately 20,000 tonnes/month. Therefore, the monthly losses of kerosene, which remain with tailings solids would be $23.3 \text{ m}^3/\text{month}$ at 0.094% kerosene and a specific gravity of 0.81. It is expected that a large proportion of the kerosene would volatilize and biodegrade in the tailings area, therefore total kerosene losses from the mill may be substantially higher. Similarly, the tertiary amine at a level of 0.01 percent reports to the tailings solids at the rate of approximately 2 tonnes/month.

The levels of tertiary amine are surprisingly high as the expected usage would be in the range of 1/20 or less that of kerosene. In addition amines were not expected to be concentrated in the solid phase yet seepage levels measured were only 1 part per billion.



7.3 MINERALOGY

The Saskatchewan Research Council (see Appendix C) undertook a mineralogical examination of selected tailings samples. Methods and procedures employed are presented in Appendix C. In general, mineralogical examination was undertaken by a combination of x-ray diffraction and microscopic methods.

Two samples labelled A3 and A7 were analyzed. General conclusions could be drawn relating to the abundance of the primary constituents but direct quantitative estimates especially for arsenical and heavy metal minerals could not be drawn. Table 7.2 provides a summary of the primary minerals present and their approximate weight percent.

A brief discussion of the results is provided.

7.3.1 Major Minerals Identified

Quartz (SiO_2)

Silica is the most abundant mineral present. As shown on Table 7.1 of Section 7.2 the average silicon content in the tailings samples was 24 percent. This translates to approximately 48 percent quartz assuming 95% of silica is present as SiO_2 .

Gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) and Bassanite ($2\text{CaSO}_4 \cdot \text{H}_2\text{O}$)

Calcium sulphate minerals gypsum and bassanite were both present with the predominant species being gypsum.

Assuming 95% of the sulphate is present as gypsum, (other sulphates such as BaSO_4 , ettringite etc. are present) then from Table 7.1 approximately 25% by weight of the tailings solids is gypsum.



TABLE 7.2

**KEY LAKE PROJECT
MONITORING OF LAYERED URANIUM TAILINGS - PHASE I**

ESTIMATED MINERALOGICAL CONTENT

<u>Mineral/Compound</u>	<u>Formula</u>	<u>Wt. %</u>
Major Constituents		
Quartz	SiO ₂	48
Gypsum	CaSO ₄ ·2H ₂ O(2CaSO ₄ ·H ₂ O)	26
Graphite	C	2*
Illite, Trichlorite	(K, Al, Mg, Si, Ti, O, OH, Al, Mg, Si, O, OH)	7.4
Etringite	Ca ₆ Al ₂ (SO ₄) ₃ (OH) ₁₂ ·26H ₂ O	3.7
Calcium Arsenate	Ca ₃ (AsO ₄) ₂ ·3H ₂ O	2.0
Calcite	CaCO ₃	3.0
Gerardorfite	NiAsS	0.8
Nickel Compounds	NiS, Ni(OH) ₂ , Ni ₃ FeS ₂	2.0
Iron Compounds	Fe ₂ O ₃ , FeS ₂ , Fe(OH) ₃	3.2
Minor Constituents		
Cobalt Compounds	CoS, Co(OH) ₂	0.1
Uranium Compounds	U(adsorbed), hydrated oxides	< .1
Zinc Compounds	ZnS, ZnFeS, Zn(OH) ₂	< .1
Lead Compounds	PbS, Pb(OH) ₂	< .1
Copper Compounds	CuS, Cu(OH) ₂	< .1
<u>Mineral/Compound</u>	<u>Formula</u>	<u>Wt. %</u>
Trace Constituents		
Phosphates	-	< .01
V	-	< .01
Ti	-	< .01
Mn	-	< .001
Cd	-	< .001
Th	-	< .001
Mo	-	< .001
Y	-	< .001
Ba	-	< .001
Cr	-	< .001
La	-	< .001
Sr	-	< .0001
Be	-	< .0001
TOTAL		100.2%

* assumed, no measurements available

Graphite (C)

Carbon is relatively abundant in the tailings samples but no estimate of the content is provided. Levels are likely to be in the 1 to 3 percent range.

Ettringite $(\text{Ca}_6\text{Al}_2(\text{SO}_4)_3(\text{OH})_{12}\cdot 26\text{H}_2\text{O})$

Ettringite was a common mineral found in the samples. Based upon quantitative mineralogy by SRC, the approximate ratio of ettringite to quartz is 7.7:100. Given the estimated quartz level of 50% the estimated ettringite content would be 3.7%.

Clay Minerals

The clay minerals most common to the Athabasca Basin uranium ores are illite and trichlorite and both were identified in large quantities in the tailings. The clay mineral content was estimated to be approximately 7.4 percent (using the same procedure for ettringite).

Other Major Minerals (not identified)

Two minerals compounds specifically not identified are calcium arsenate and calcite (and or dolomite).

Calcium Orthoarsenate $(\text{Ca}_3(\text{AsO}_4)_2\cdot 3\text{H}_2\text{O})$

Calcium arsenate is present from the bulk precipitation of dissolved arsenic by lime. Sheritt Gordon (1979) anticipate approximately 70% of the arsenic present in the ore would dissolve and reprecipitate as an arsenate. Given an average level of 1.1 percent arsenic in the tailings and 70% as calcium arsenate, then the calcium arsenate content of the tailings would be approximately 2.0 percent.



Calcite (CaCO_3)

Although carbonate minerals and re-assay of the sample were not found in the mineralogical examination, chemical testing did indicate approximately 3 percent carbonate content in the tailings. The carbonate is likely present as a result of CO_2 dissolution followed by CaCO_3 precipitation and calcite mineral in the lime used for bulk neutralization. Assuming calcium carbonate is the primary mineral, then the calcite content is 5 percent.

7.3.2 Heavy Metals

The primary species identified were sulphides, and iron oxides. A brief description of these mineral species and content follows.

Gersdorffite (NiAsS)

This mineral was identified to be the most abundant heavy mineral and as expected does contain some cobalt. Given that all arsenic not precipitated with $\text{Ca}_3(\text{AsO}_4)_2$ is present as gersdorffite then the estimated NiAsS content is approximately 0.3%.

Other Nickel Minerals ($\text{Ni}(\text{OH})_2$, NiS , $(\text{Ni}, \text{Fe})\text{S}_2$)

The predominant nickel mineral is millerite NiS with some bravoite $((\text{Ni}, \text{Fe})\text{S}_2)$ identified. Nickel hydroxide was not identified but certainly would be present as a result of precipitation with lime. Assuming the remaining nickel not tied up with NiAsS occurs as NiS or $\text{Ni}(\text{OH})_2$ then the estimated content in the tailings of these nickel compounds is 2.0 percent.



Iron Containing Minerals

(Fe_2O_3 , HFeO_2 , FeS_2 , ZnFeS , CuFeS_2 , $\text{Fe}(\text{OH})_3$)

Several iron minerals were identified with hematite (Fe_2O_3) the most prevalent. Sphalerite (ZnFeS) chalcopyrite (CuFeS_2), pyrite (FeS_2) and goethite (HFeO_2) were also measured. Hydrated oxides and hydroxides would also be present. Assuming the majority of iron is present as Fe_2O_3 then the average iron mineral content is approximately 3.2 percent.

Magnesium Hydroxide ($\text{Mg}(\text{OH})_2$)

Magnesium hydroxide was not identified in the mineralogical test work but would be present from the bulk neutralization with lime. For example the tailings discharge on November 21 contained 410 mg/L of magnesium at a pH of 6.45. When this pH is raised above 9.0 to 10 much of this magnesium is precipitated (as noted on other occasions) when the pH of the discharge was highly alkaline. It is estimated that about half of the magnesium present in the tailings solids is there as clay minerals. Therefore much of the remaining magnesium would be presents as an hydroxide. The resultant $\text{Mg}(\text{OH})_2$ content is aproximately 1%.

Uranium Minerals

The uranium content of tailings was measured (see Table 7.1) to average 0.05%. No uranium minerals were identified, however, a short leaching experiment by SRC indicated that uranium was easily mobilized and indicative of either an adsorbed species or hydrated oxide rather than as mineral occurrences which has undergone a strong acid leach. Assuming its presence as U_3O_8 then the uranium mineral content is $\angle$ 0.1 percent.



Cobalt Minerals

Cobalt is associated with NiAsS and linnaeite (CO_3S_4) was also identified. Cobalt would also be present as an hydroxide. The total cobalt mineral content is approximately 0.1%.

Miscellaneous Mineral/Metals

Several trace minerals including salena (PbS) covellite (CuS) and rutile (TiO_2) were identified in mineralogical test work. Trace elements measured in order of occurrence included P, V, Zr, Mn, Cd, Th, Mo, Y, Ba, Cr, La, Sr and Be.

7.3.3 Summation

The relative percentage of each mineral/compound type is provided in Table 7.2. As shown in the table quartz and gypsum constitute almost 75% of the total tailings mass. Other minerals are undoubtedly present however, it is not likely that they represent a large mass. The total percent weight identified was 100.2% of the total tailings mass.

The mineral analysis on Table 7.2 is not in complete balance with the chemical analysis on Table 7.1. This imbalance should be expected as mineralogical work was undertaken on only 2 samples and the mineralogical description is an inexact representation of the composition of the sample. However the balance is reasonable as illustrated below for calcium and sulphate.

The average calcium content measured was 7.7%. Calcium is contained in 4 principal mineral compounds; $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$, CaCO_3 , $\text{Ca}_6\text{Al}_2(\text{SO}_4)_3(\text{OH})_{12} \cdot 26 \text{H}_2\text{O}$ and $\text{Ca}_3(\text{AsO}_4)_2$. The expected calcium content based upon mineralogical analysis is 9.1% as shown.



<u>Mineral</u>	<u>Wt % of Tailings</u>	<u>% Calcium</u>
$\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$	26	5.9
CaCO_3	5	2.0
$\text{Ca}_6\text{Al}_2(\text{SO}_4)_3(\text{OH})_{12} \cdot 26\text{H}_2\text{O}$	3	0.6
$\text{Ca}_3(\text{AsO}_4)_2 \cdot 3\text{H}_2\text{O}$	2	0.6
Total Calcium Content		9.1%

Note the calcium content of the mineralogical samples A3 and A7 was 8.7 percent which agrees well the predicted calcium content.

Similarly the average sulphate content measured was 15.4%. Primary sulphate sources are $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ and $\text{Ca}_6\text{Al}_2(\text{SO}_4)_3(\text{OH})_{12} \cdot 26\text{H}_2\text{O}$. The sulphate content from mineralogical analysis would be 15.2%.

Cation Exchange Capacity

Two samples A3 and A7 were analyzed for their cation exchange capacities (CEC). The CEC measured were 2.2 and 5.4 meq/100g. Beals (1985) indicates that CEC is predominantly a function of the clay fraction of a soil and provides the following imperial relationship.

$$\text{CEC} = (\% \text{ clay} / 2) + (\% \text{ organic content} \times 2)$$

For Key Lake tailings the % clay size portion was not obtained and much of the tailings is chemical precipitates. Using the clay mineral content of 7.4% as the clay fraction, and assuming the organic content was zero, using Beals formula we would predict a CEC of 3.7 meq/100g which compares well with those measured.



SECTION 8.0 - CHEMISTRY - TAILINGS LIQUIDS

8.1 PROGRAM OUTLINE

The program for sampling tailings liquids is outlined in Section 3.5 and on Figure 7.1. The program included samples of incoming tailings water, effluents, seepage, porewater and simulated long term leaching tests.

The primary objectives of the program were to:

- Provide chemical and radiological characteristics of tailings liquids.
- Provide basic data for input into a geochemical model.

8.2 PRESENTATION OF RESULTS

8.2.1 Tailings Influent

Monthly grab samples of the discharge to the tailings basin were obtained from September through March. The results of the analysis are provided in Table 8.1.

As a general rule, the pH of the tailings discharge is maintained above 11.0 and contains free lime in solution. However, on two sampling occasions, pH levels were measured at below 7.0. The primary chemical controls on the system are the oxidizing conditions, high pH with free hydroxyl alkalinity, the ionic strength and the calcium and sulphate content.

The following is a short discussion on the principal observations of the tailings influent.



TABLE 8.1

KEY LAKE PROJECT
MONITORING OF LAYERED URANIUM TAILINGS - PHASE 1

ANALYSES OF INCOMING TAILINGS

Parameter	SAMPLING DATE					Units	SAMPLING DATE					Units	SAMPLING DATE								
	Sept.16	Oct.16	Nov.21	Jan.9	Feb.13		March 9	Sept.16	Oct.16	Nov.21	Jan.9		Feb.13	March 9	Sept.16	Oct.16	Nov.21	Jan.9	Feb.13	March 9	
Ag	< 0.012	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	mg/l	Zn	0.23	0.002	0.47	0.29	0.012	0.005	mg/l	0.23	0.002	0.47	0.29	0.012	0.005
Al	0.04	0.12	0.05	< 0.005	.15	.13	mg/l	Zr	-	-	< 0.001	< 0.001	< 0.001	0.002	mg/l	-	-	< 0.001	< 0.001	< 0.001	0.002
As	-	-	2.2	.763	2.0	4.6	ug/l	U	20 ⁻¹	3.2-0.3	100-10	36-2	20-1	25-2	ug/l	20 ⁻¹	3.2-0.3	100-10	36-2	20-1	25-2
B	0.03	0.04	0.52	0.02	.31	0.10	mg/l	Pb-210	25	-	3.0	45	0.40	35	Bq/l	25	-	3.0	45	0.40	35
Ba	0.12	0.09	0.010	.12	.027	0.093	mg/l	Pb-210	0.5	-	-	-	-	-	Bq/l	0.5	-	-	-	-	-
Be	< 0.001	< 0.001	< 0.001	< .001	< .001	< .001	mg/l	Ra-226	350	-	25	420	55	350	Bq/l	350	-	25	420	55	350
Ca	990	530	520	1050	534	720	mg/l	Ra-226 (total)	-	420	-	-	-	-	Bq/l	-	420	-	-	-	-
Cd	0.004	0.036	< 0.001	.005	.001	0.004	mg/l	Th-228	-	-	0.13	0.35	0.07	0.19	Bq/l	-	-	0.13	0.35	0.07	0.19
Co	< 0.001	< 0.001	0.41	< .001	.003	< 0.001	mg/l	Th-230	4.0	-	0.63	4.5	0.30	3.0	Bq/l	4.0	-	0.63	4.5	0.30	3.0
Cr	0.022	0.008	0.024	.015	.012	0.009	mg/l	Th-232	-	0.13	-	0.40	0.02	0.25	Bq/l	-	0.13	-	0.40	0.02	0.25
Cu	0.009	0.005	0.008	.007	.008	0.048	mg/l	*Alkalinity (4.3)	-	-	-	500+	0	336	mg/l	-	-	-	500+	0	336
Fe	0.049	0.044	0.032	.048	.036	0.064	mg/l	*Alkalinity (4.5)	-	44.5	-	-	15	369	mg/l	-	44.5	-	-	15	369
K	4.9	7.1	12	15	30	8.5	mg/l	Ammonia-N	-	-	33	11	13	7.3	mg/l	-	-	33	11	13	7.3
Mg	12	1.1	510	.17	130	0.10	mg/l	Carbonate	-	-	NEL	-	-	-	mg/l	-	-	NEL	-	-	-
Mn	< 0.001	0.017	1.9	.002	.13	< 0.001	mg/l	Chloride	-	-	19	347	26	14	mg/l	-	-	19	347	26	14
Mo	2.1	1.5	0.11	.99	.48	3.7	mv	Eh	-95	-187/-237*	-	269	395/237*	125*/142	mv	-95	-187/-237*	-	269	395/237*	125*/142
Na	15	76	18	113	210	60	mg/l	Hydroxide	-	-	-	-	-	-	mg/l	-	-	-	-	-	-
Ni	0.011	0.022	95	.010	.29	0.018	mg/l	Nitrate-N	-	-	-	-	-	-	mg/l	-	-	-	-	-	-
P	0.2	0.16	0.38	0.05	.3	0.1	mg/l	Nitrite-N	-	-	-	-	-	-	mg/l	-	-	-	-	-	-
Pb	0.18	< 0.003	0.009	.28	< 0.005	< 0.003	mg/l	pH	11.9	9.3	6.41	12.1	6.89*/6.85	11.8*	mg/l	11.9	9.3	6.41	12.1	6.89*/6.85	11.8*
Sb	-	-	0.001	< .0005	< 0.005	0.002	mg/l	Sulphate	1400	1880	3450	1310	2370	1540	mg/l	1400	1880	3450	1310	2370	1540
Se	-	-	0.008	0.001	0.005	0.02	mg/l	T.D.S.	-	-	5220	3490	3660	2760	mg/l	-	-	5220	3490	3660	2760
Si	-	-	0.3	0.6	0.2	0.8	umho/cm	*Conductivity	-	2760	4320	6810	3150	3490	umho/cm	-	2760	4320	6810	3150	3490
Ti	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	ug/l	Isooctanol	-	-	-	-	-	-	ug/l	-	-	-	-	-	-
V	0.06	0.21	0.06	0.06	0.07	0.13	ug/l	Kerosene	-	-	-	-	-	-	ug/l	-	-	-	-	-	-
W	0.94	1.1	< 0.01	0.03	0.22	0.32	ug/l	Tertiary Amines	-	-	-	-	-	-	ug/l	-	-	-	-	-	-

*By KLMC otherwise all analyses by SRC.

- Many metals are at very low concentrations. Those with geometric means of $< .01$ mg/L include Ag, Be, Cd, Co, Cu, Sb, Se, Ti and Zr.
- Other contaminants at inconsequential levels include Al, B, Ba, Cr, Fe, K, Mg, Na, NO_3 , NO_2 and Cl.
- When pH levels are > 11.5 and < 7.0 amphoteric metals Pb and Zn are also $> .01$ mg/L.
- Major contaminants (based upon water quality objectives) would be As, Ni, Ra-226, Pb-210 and NH_3 .
- Elements Mo and W and to a lesser extent Cr are at elevated concentrations. These are all transition elements of the 6b family in the periodic table.
- Pb-210 like elemental lead is more soluble at pH levels above 11.5 and at acidic pH levels.
- With the exception of one sample, all thorium isotopes were measured at or below 0.4 Bq/L.
- Uranium levels at $< .1$ mg/L are surprisingly low as U(VI) is very soluble under highly alkaline conditions.
- High nickel concentrations occur when the tailings discharge pH is below 7.0.



8.2.2 Tailings Pond Effluent (Surface Runoff)

Tailings pond effluent was sampled on two occasions, once in September and again in October. The analyses are provided in Table 8.2. The tailings effluent samples are very similar in nature to the tailings discharge. Very little mobilization or precipitation of contaminants has occurred except for the amphoteric metals Pb and Zn whose concentrations are markedly reduced at the slightly lower pH conditions. Again Mo and W and to a lesser degree Cr are at elevated levels.

8.2.3 Tailings Pond Seepage

Three tailings pond seepage samples were collected, one in September, one in October and one in January. The analyses of the samples are provided in Table 8.3. The most notable characteristics are listed below.

- The pH of the seepage is markedly reduced to 7-7.5 range.
- With two exceptions all constituents excluding monovalent elements are at lower concentrations in seepage than in tailings influent or effluent.
- Only Ra-226 is present at levels exceeding 0.5 Bq/L.

Samples of seepage collected by KLMC from the seepage collection system in 1984 had comparable constituent levels with an average pH of 8.9.

8.2.4 Tailings Porewaters

Six porewater samples were extracted one from each core sample A3, A7, A8, B1, B2 and B3. The analyses for the porewaters for A8, B1,



TABLE 8.2

KEY LAKE PROJECT
MONITORING OF LAYERED URANIUM TAILINGS - PHASE 1

ANALYSES OF SURFACE RUN-OFF

Parameter	SAMPLING DATE		Units	Parameter	SAMPLING DATE		Units
	Sept. 17	Oct. 16			Sept. 17	Oct. 16	
Ag	0.002	< 0.001	mg/l	Zn	0.001	0.001	mg/l
Al	0.47	0.22	mg/l	Zr	-	-	mg/l
As	-	-	ug/l	U	13 [±] 1	3.2 [±] 0.3	mg/l
B	0.09	0.27	mg/l	Pb-210	3.0	-	Bq/l
Ba	0.049	0.032	mg/l	Po-210	0.15	-	Bq/l
Be	< 0.001	< 0.001	mg/l	Ra-226	210	-	Bq/l
Ca	780	655	mg/l	Ra-226 (total)	-	270	Bq/l
Cd	0.009	0.001	mg/l	Th-228	-	-	Bq/l
Co	< 0.001	< 0.001	mg/l	Th-230	2.0	-	Bq/l
Cr	0.022	0.011	mg/l	Th-232	-	-	Bq/l
Cu	0.006	0.008	mg/l	Alkalinity (8.3)	-	-	mg/l
Fe	0.049	0.046	mg/l	Alkalinity (4.3)	-	-	mg/l
K	7.8	17	mg/l	Ammonia-N	-	-	mg/l
Mg	0.16	< 0.01	mg/l	Carbonate	-	-	mg/l
Mn	< 0.001	0.001	mg/l	Chloride	-	-	mg/l
Mo	1.3	0.38	mg/l	*Eh	-123*	-118*/-190	mv
Na	23	92	mg/l	Hydroxide	-	-	mg/l
Ni	0.011	0.005	mg/l	Nitrate-N	-	-	mg/l
P	0.2	0.07	mg/l	Nitrite-N	-	-	mg/l
Pb	0.02	< 0.005	mg/l	pH	11.3	11.5	
Sb	-	-	mg/l	Sulphate	1720	1590	mg/l
Se	-	-	mg/l	T.D.S.	-	-	mg/l
Tl	< 0.001	< 0.001	mg/l	Conductivity	-	3180	umho/cm
V	0.14	0.06	mg/l				
W	0.89	0.45	mg/l				

*SRC otherwise by KLMC.

TABLE 8.3

KEY LAKE PROJECT
MONITORING OF LAYERED URANIUM TAILINGS - PHASE I

ANALYSES OF SEEPAGE

Parameter	SAMPLING DATE				Units	Parameter	SAMPLING DATE				Units	KLMC 1984 Monitoring Data
	Sept. 17	Oct. 16	Jan. 7				Sept. 17	Oct. 16	Jan. 7			
Ag	< 0.001	0.003	< .001		mg/l	V	0.07	< 0.01	< .01		mg/l	.01 - .21
Al	0.08	0.037	< .005		mg/l	W	0.31	0.084	.06		mg/l	-
As	-	62	76		ug/l	Zn	0.062	0.076	.21		mg/l	.01 - .22
B	0.04	0.02	.02		mg/l	Zr	-	-	< .001		mg/l	-
Ba	0.04	0.061	.047		mg/l	U	132-11	42-3	60-6		ug/l	13 - 740
Be	< 0.001	< 0.001	< .001		mg/l	Pb-210	0.43	-	0.07		Bq/l	.02 - 1.6
Ca	330	374	347		mg/l	Po-210	0.09	-	-		Bq/l	.14 - 16
Cd	0.01	< 0.001	.001		mg/l	Ra-226	45	-	12		Bq/l	2.6 - 25
Co	< 0.001	0.009	.003		mg/l	Ra-226 (total)	-	10	-		Bq/l	-
Cr	0.014	0.004	.006		mg/l	Th-228	-	-	0.09		Bq/l	-
Cu	0.009	0.007	.009		mg/l	Th-230	0.20	-	1.40		Bq/l	.03 - .43
Fe	0.033	3.8	.042		mg/l	Th-232	-	-	0.07		Bq/l	-
K	7.8	8.6	8.9		mg/l	*Alkalinity (4.3)	-	-	0		mg/l	-
Mg	0.63	3.9	2.1		mg/l	*Alkalinity (4.3)	-	38.5	26.7		mg/l	-
Mn	0.037	4.2	1.3		mg/l	Ammonia-N	-	-	34		mg/l	-
Mo	0.72	0.48	.85		mg/l	Chloride	-	-	16		mg/l	1.5 - 18
Na	32	47	24		mg/l	Elect	-	-243	+374/+424		mv	-
Ni	0.039	0.041	.094		mg/l	Hydroxide	-	-	NIL		mg/l	-
P	0.08	0.06	0.03		mg/l	Nitrate-N	-	-	0.03		mg/l	-
Pb	0.02	< 0.005	< .005		mg/l	Nitrite-N	-	-	< 0.005		mg/l	-
Sb	-	-	.002		mg/l	pH	7.4	7.1	7.43			6.5 - 11.4
Se	-	-	< .001		mg/l	Sulphate	1470	1150	1400		mg/l	435 - 1467
Si	-	-	1.3		mg/l	T.D.S.	-	-	2160		mg/l	1280 - 2500
Tl	< 0.001	< 0.001	< .001		mg/l	*Conductivity	-	-	2030		umho/cm	-
						Isodecanol	-	-	100		ug/l	-
						Kerosene	-	-	0.2		ug/l	-
						Tertiary Amines	-	-	1		ug/l	-

* By KLMC otherwise by SRC.

B2 and B3 are provided on Table 8.4. The extent of the analyses was limited by sample volume. The principal observations are:

- pH levels lie between influent and seepage pH values..
- Arsenic levels are substantially higher than in the seepage.
- Radium levels are higher than in seepage.
- Uranium levels are notably very low.
- Concentrations of other constituents are similar to influent, effluent and seepage concentrations.

8.2.5 Leaching Studies

One of the objectives of the program was to assess what chemical changes may occur over time as contaminants are washed from the tailings by infiltrating precipitation. Two approaches were considered, one using column leaching studies and the other using batch-agitated shaker flask leaching studies. Considering the short time available and the low permeability of the tailings it was decided that the column leaching studies would not be appropriate. Therefore shaker studies were employed.

In the test, 2 core samples A3 and A7 were washed with deionized water 3 times. On each occasion the solids were filtered and the leachate was analyzed. The wash ratio (total wt. of water used to leach solids divided by the weight of solids) selected was approximately 12:1. This was equivalent to the amount of water which could potentially infiltrate into the tailings over a 1000 year period. In actuality the tailings low permeability would substantially reduce the infiltration rate.



TABLE 8.4

KEY LAKE PROJECT
MONITORING OF LAYERED URANIUM TAILINGS - PHASE I

PORE WATER ANALYSES
CORES A8, B1, B2 AND B3

Analysis	Units	A8	B1	B2	B3
CO ₃	mg/l	72	58	58	72
SO ₄	mg/l	1640	1450	1620	1650
Ca	mg/l	620	582	611	627
Mg	mg/l	4	2	4	1
Al	mg/l	0.58	0.66	0.42	0.27
As	ug/l	2200	460	1600	1800
Co	mg/l	< 0.005	< 0.005	< 0.005	< 0.005
Fe	mg/l	0.019	0.024	0.013	0.026
Mo	mg/l	0.54	0.43	0.82	0.72
Ni	mg/l	0.082	0.041	0.082	0.087
Si	mg/l	4.1	3.0	2.6	3.9
Eh	mv	275	227	276	276
pH		9.48	10.43	9.33	9.46
Pb-210	Bq/l	0.13	0.70	0.35	0.22
Ra-226	Bq/l	40	30	40	55
Th-230	Bq/l	1.6	0.80	0.65	0.90
U	ug/l	4.3	1.4	1.8	5.0

The results of the leaching studies for core A-3 and A-7 are contained on Table 8.5 and 8.6 respectively. The major observations are noted below.

- The pH of the leachate decreased with each washing.
- As pH drops with sequential washes, arsenic solubility increases. Nickel concentrations also rise.
- Ra-226 is the only mobile radionuclide and the mobility increases with increasing wash ratio.
- Conductivity remains elevated and is controlled by gypsum solubility.
- Cl, NH₃, K and Na are substantially reduced.
- Levels of Ca, SO₄, Al, Ba, Fe, Cu, Pb, Sb, V, W, Zn are not substantially effected by leaching.
- Molybdenum concentrations decrease with increasing wash ratio.

8.3 DISCUSSION OF RESULTS

8.3.1 General

A summary of the range of analytical results for selected key constituents for all tailings liquids tested is provided in Table 8.7. Also provided for comparison are the column leaching results on the bulk neutralized Key Lake tailings as measured by Sherrit Gordon (1979) and the relevant Saskatchewan uranium mining effluent discharge limits.



TABLE 8.5

KEY LAKE PROJECT
MONITORING OF LAYERED URANIUM TAILINGS - PHASE I

ANALYSES OF PORE WATER AND LEACH WATER

CORE A3

Analysis	Units	Pore Water	Leach 1 Water	Leach 2 Water	Leach 3 Water	Analysis	Units	Pore Water	Leach 1 Water	Leach 2 Water	Leach 3 Water
CO ₃	mg/l	14	0	-	0	Mg	mg/l	2.9	5.6	-	1.5
Cl	mg/l	24	53	-	4	Mn	mg/l	0.033	0.44	-	.018
HCO ₃	mg/l	0	0	-	95	Mo	mg/l	1.2	1.0	-	0.46
OH	mg/l	16	0	-	0	Na	mg/l	43	2.5	-	21
SO ₄	mg/l	906	1620	-	1440	Ni	mg/l	0.017	0.046	-	.26
NH ₃ -N	mg/l	40	9.7	-	2.1	Pb	mg/l	< .02	0.03	-	< 0.02
NO ₂ -N	mg/l	0.02	< 0.005	-	0.44	Sb	ug/l	.005	0.01	-	.01
NO ₃ -N	mg/l	< .005	< .005	-	.05	Si	mg/l	1.8	2.0	-	1.7
B	mg/l	< .05	< .05	-	1.3	Tl	mg/l	< .005	< .005	-	< 0.005
P	mg/l	< .02	< .02	-	< .02	V	mg/l	.15	.08	-	.14
Se	mg/l	< .004	< .004	-	< .004	W	mg/l	.23	.39	-	.44
Ag	mg/l	< .005	< .055	-	.019	Zn	mg/l	.032	.05	-	.038
Al	mg/l	.32	.28	-	.38	Zr	mg/l	< .005	< .005	-	< .005
As	ug/l	370	1800	-	2600	Eh	mv	211	395	412	350
Ba	mg/l	.042	.058	-	.041	pH		9.98	9.19	8.12	7.8
Be	mg/l	< .005	< .005	-	< 0.005	TDS	mg/l	-	-	-	-
Ca	mg/l	343	660	-	610	Conductivity	umho/cm	-	-	2380	-
Cd	mg/l	< .005	< .006	-	.013	Re-226	Bq/l	9.5	35	-	40
Co	mg/l	< .005	< .005	-	< .005	Th-228	Bq/l	< 0.01	.05	-	.10
Cr	mg/l	< .005	< .005	-	.024	Th-230	Bq/l	0.08	.35	-	1.0
Cu	mg/l	.023	.027	-	.047	Th-232	Bq/l	0.02	.02	-	.14
Fe	mg/l	.070	.071	-	-						
K	mg/l	17	15	-	-						

TABLE 8.6

KEY LAKE PROJECT
MONITORING OF LAYERED URANIUM TAILINGS - PHASE I

ANALYSES OF PORE WATER AND LEACH WATER

CORE A7

Analysis	Units	Pore Water	Leach 1 Water	Leach 2 Water	Leach 3 Water	Analysis	Units	Pore Water	Leach 1 Water	Leach 2 Water	Leach 3 Water
CO ₃	mg/l	43	0	-	0	Mg	mg/l	.61	.89	-	0
Cl	mg/l	35	26	-	7	Mn	mg/l	< .005	< .005	-	< .005
HCO ₃	mg/l	0	29	-	48	Mo	mg/l	1.0	.93	-	.28
OH	mg/l	41	0	-	0	Na	mg/l	26	19	-	3.8
SO ₄	mg/l	1340	1560	-	1420	Ni	mg/l	.016	.033	-	.026
NH ₃ -N	mg/l	25	3.1	-	.01	Pb	ug/l	.04	.04	-	< .02
NO ₂ -N	mg/l	.04	.04	-	< .005	Sb	mg/l	.01	.004	-	.01
NO ₃ -N	mg/l	< .005	.009	-	< .005	Si	mg/l	2.2	3.4	-	3.0
B	mg/l	< .05	< .05	-	< .05	Ti	mg/l	< .005	< .005	-	< 0.005
P	mg/l	< .02	< .02	-	< .02	V	mg/l	.16	.19	-	.15
Se	mg/l	< .004	< .004	-	< .004	W	mg/l	.25	.33	-	.25
Ag	mg/l	< .005	.055	-	.009	Zn	mg/l	.020	.004	-	< .005
Al	mg/l	.13	.14	-	.14	Zr	mg/l	< .005	< .005	-	< .005
As	ug/l	260	1600	-	2080	Eh	mv	250	393	395	468
Ba	mg/l	.056	.034	-	.034	pH		11.14	7.35	7.23	6.68
Be	mg/l	< .005	< .005	-	< .005	TDS	mg/l	-	2440	-	2250
Ca	mg/l	620	640	-	615	Conductivity	umho/cm	-	2590	2390	2340
Cd	mg/l	< .005	.01	-	.01	Ra-226	Bq/l	10	30	-	55
Co	mg/l	< .005	.011	-	< 0.05	Th-228	Bq/l	.02	.08	-	.10
Cr	mg/l	.018	.022	-	.024	Th-230	Bq/l	.15	.40	-	.50
Cu	mg/l	.008	.020	-	.005	Th-232	Bq/l	.04	.07	-	.10
Fe	mg/l	.16	.087	-	.077						
K	mg/l	6	11	-	5						

TABLE 8.7

KEY LAKE PROJECT
MONITORING OF LAYERED URANIUM TAILINGS - PHASE I

COMPARISON OF TAILINGS LIQUID AND LEACHATE ANALYSIS

	Tailings Influent	Tailings Runoff Effluent	Porewater	Seepage	Leaching Tests Batch Agitated (SRC 1985)	Column Studies (Sherritt Gordon 1979)	Seabachewan Authorized avg. monthly concentrations
As	.763-2.2	-	.26-2.2	.062-.076	1.6-2.6	1.8-6.7	0.3
Cr	.008-.028	.011-.022	<.005	.004-.018	<.005-.026	<.01-0.1	-
Mn	0.11-2.1	.38-1.3	.43-1.2	.48-.83	0.28-1.0	0.2-3.3	0.3**
Ni	.01-.95	.005-.011	.016-.087	.041-.098	.025-.26	<.1-1.6	0.3
Pb	<.005-.28	<.005-.02	<.02-.04	<.005-.02	<.02-.04	<.1-.7(6.3*)	0.2
Si	0.2-0.6	-	1.8-4.1	1.3	1.7-3.8	3.1-48.8	-
U	.0035-.1	.0032-.013	.0018-.005	.042-.132	-	0.3-3.7	1.0
Zn	.002-.29	.001	.02-.032	.042-.21	.004-.05	<.01-4.0	0.3
W	.01-1.1	.45-.89	.28-.25	.06-.31	.25-.44	-	-
Re-226 (Bq/L)	25-470	270	9.5-55	10-45	30-55	35-41	0.37
Pb-210 (Bq/L)	0.4-25	3	0.13-0.7	.45	-	-	1.85
Tb-230 (Bq/L)	0.5-4.0	2	.08-1.6	0.2	.35-1.0	-	1.85
Po-210 (Bq/L)	0.5	.15	-	.09	-	-	-
pH	6.41-12.1	11.3-11.5	9.33-11.18	7.1-7.43	6.68-9.19	5.6-9.9	5-9.5
Ca	520-1050	655-780	582-627	374-550	410-660	364-840	-
SO ₄	1310-3450	1590-1720	1340-1650	1150-1470	1420-1620	1500-1950	-

* likely an erroneous measurement
 ** level may be revised upward

A short description of the chemistry of the major constituents and the levels observed is presented in this section and geochemical modelling aspects of selected species are expanded in Chapter 9.0.

8.3.2 Arsenic

Arsenic solubility is strong function of pH and calcium content. At elevated calcium and pH levels arsenic concentrations are low and as pH or calcium concentrations decrease arsenic solubility increases.

Long term leaching studies by both the batch-agitated, and column method give similar results. With arsenic concentrations ranging from 1.6 - 2.6 in the agitated studies to 1.8 to 6.7 in the column studies. The higher levels in the column studies are likely attributable to the lower pH of several leachate samples.

Seepage levels of arsenic are very low at 0.062 and 0.076 yet porewater levels were as high as 2.2 mg/L. This reduction is most likely attributable to adsorption of arsenic in the sand filter blanket of the seepage collection system.

The chemistry of arsenic is similar to that of phosphorus with its solubility in nature primary controlled by alkaline earth elements such as Ca and barium as well as iron compounds. Arsenic has two common valencies (+3 and +5) in nature. The reduced species As (III) is highly mobile while As (V) is readily precipitated as noted above. The drinking water standard for arsenic is 0.05 mg/L with an objective level of 0.005 mg/L. The mining effluent regulations for arsenic discharge are 0.5 mg/L. As such, arsenic is a long term contaminant.



8.3.3 Chromium, Molybdenum and Tungsten

Molybdenum, tungsten and to a lesser extent chromium are at elevated levels in the seepage. Chromium levels would meet all industrial discharge criteria and no discharge or drinking water criteria currently exist for either molybdenum or tungsten. Molybdenum levels in the tailings solids were only at 13 mg/kg and tungsten was not even detected from the heavy metals flotation in the mineralogical work by SRC. Chromium was present at a levels of 10 mg/kg. Given the low levels of these metals, they are most unlikely to be mobilized in significant concentrations and at the current estimated long term levels based upon the leaching studies, they are of secondary concern.

8.3.4 Nickel, Lead and Zinc

Nickel, lead and zinc are primary present in the tailings as precipitated hydroxides or carbonates and as such long term levels would be a direct function of pH and alkalinity. Only if pH levels drop into the 6-7.0 range would these three metals exceed discharge standards.

Measurements of nickel in porewater and seepage were less than 0.1 mg/L and increased to about 0.25 mg/L in the batch agitated leaching studies. The column studies produced levels as high as 1.6 mg/L nickel with correspondingly lower pH levels.

Lead levels were consistently less than 0.05 mg/L in all porewater seepage and batch-agitated leaching studies. The column studies produced more elevated levels with 0.1 mg/L being typical. One value of 0.7 mg/L was measured at pH 5.6 in the column study.



Zinc solubility like lead was low for the porewater, seepage and batch-agitated tests. Maximum levels measured were 0.21 mg/L in the seepage. Column studies produced similar results with zinc levels typically ranging from < 0.1 to 0.28 mg/L. One elevated zinc measurement of 4 mg/L again corresponds to the one low pH seepage sample (3.6).

8.3.5 Radionuclides

The primary controls on radionuclide mobility are pH and sulphate content.

Radium - 226 is a relatively mobile nuclide. Mill discharge concentrations are ranged from 25 to 420 Bq/L reducing to 10-50 Bq/L in the porewater and seepage. KLMC monitoring data indicates levels of 10 Bq/L would be more representative of the mill discharge. The radium is most likely present as co-precipitates with alkaline earth sulphates such as BaSO_4 , CaSO_4 , etc. as well as adsorbed onto particulate surfaces. Long term mobility will therefore, among others, be a function of pH and sulphate content. At very low or very high pH levels radium may be resolubilized. For the Key Lake tailings, long term pH levels are expected to be near neutral. Therefore the dissolution of radium sulphate compounds will likely by the primary long term control mechanisms. Given the estimated gypsum content of 25%, sulphate will remain near 1500 mg/L for thousands of years in the seepage, therefore long term radium levels are not expected to change greatly and would likely be in the 10 to 50 Bq/L range. KLMC monitoring data shows the radium levels to be less than 10 Bq/L. Lower levels for the overall facility may be the result of the expected absorption in the filter blanket.



Lead - 210 is mobilized at both low and high pH levels and its solubility follows that of elemental lead. The relatively low solubility of lead in the near neutral pH range is also reflected in the Pb-210 measurements. Pb-210 levels decreased from 25 Bq/L at pH of 11.9 in the incoming tailings to less than 1 Bq/g in the porewaters and seepage. Long term levels will likely remain in the 0.5-1 Bq/L range.

Thorium - 230 solubility is a function of pH and sulphate content. At pH levels above 4.0 thorium is virtually insoluble in water. Thorium does form complexes with sulphate which can increase its solubility. As with Pb-210 long term Th-230 levels are expected to remain in the 0.5 - 1.0 Bq/L range.

Po-210 is virtually immobile in the Key Lake tailings. All measured values were less than 0.5 Bq/L. Long term concentrations are not expected to increase unless an unexpected pH drop in the seepage occurs.

8.3.6 Uranium

Uranium mobility in the tailings is primarily a function of pH, carbonate content and oxidation state. Under reducing conditions, uranium is present as U(IV) and is virtually insoluble. Under oxidizing conditions, uranium is present as U(VI) and is highly mobile. Minimum solubility for U(VI) is in the neutral ranges.

Uranium levels are consistently low with the maximum measured value being 0.132 mg/L in seepage. The column studies undertaken by Sheritt Gordon indicated uranium was mobile with levels ranging from .01 to 4 mg/L. The reason for this disparity in the data is not known. The primary difference between the current Key Lake tailings and the test tailings is the clay content. The current tailings



are believed to have much greater levels of clay. Perhaps the clay minerals serve as an exchange medium to retard uranium movement.

Alternatively arsenic may form insoluble complexes with uranium, as discussed in Section 9.3.5, decreasing its relative mobility. However, a realistic estimate of the long term levels of uranium in seepage would be 0.5-2 mg/L.

8.3.7 Organic Content

The analyses of the tailings for isodecanol, kerosene and tertiary amine produced some interesting results. As discussed in Section 7.0, both kerosene and the amine are concentrated in the solids and virtually not present in the seepage. Conversely the isodecanol is not present on the solids but is contained in the seepage at 0.1 mg/L. Tailings influent levels were measured at 0.9 mg/L isodecanol and the reduction is likely due to volatilization and biodegradation.

The levels of these contaminants are well below levels which would impart toxic or sublethal effects to aquatic biota. Therefore these organics are not considered to be long term concerns.



SECTION 9.0 - GEOCHEMICAL CONTROLS

9.1 INTRODUCTION

The chemical constituents in the Key Lake tailings porewater and the results of the tailings leachate tests have been summarized in Table 8.7. In the ensuing analysis, this data base serves as the basis for developing chemical water quality models to describe existing conditions as well as predicting changes with time.

Water quality models for tailings may contain both equilibrium and kinetic expressions. The construction of equilibrium models involves the reduction of the complexity of the system and computing the concentration of chemical species by appropriate equilibrium expressions. Such a model takes into account the major chemical constituents to calculate solubility, speciation, ionic strength, and pH. The ionic strength and the pH are used, in turn, for assessing the concentrations of minor water quality constituents of interest (i.e. arsenic, nickel, molybdenum in the present study). Kinetic expressions take into account time dependent changes in water quality. These involve oxidation/reduction reactions that may proceed in time in the tailings. Usually, the oxidation - reduction potential (Eh) is used as a guideline for determining the direction (i.e. oxidation versus reduction) of the reaction sequences.

Chemical water quality models are mathematical expressions that only approximate the real world. From previous studies it has become evident that natural water quality cannot be reproduced exactly. Often, wide variations in equilibrium constants for the same metal complexes have been published by various authors. The purpose of the models developed in the ensuing chapter is to assess the geochemical control process and water quality trends. For these reasons, it is advantageous to use simple models



that provide an understanding of the predominant geochemical reactions in the Key Lake tailings.

9.2 PRIMARY GEOCHEMICAL CONTROL

The most evident feature of Key Lake tailings porewater chemistry is the predominance of calcium and sulphate in the water phase. Thus, a model for the primary geochemical control was derived on the basis of gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) as the stable solids phase and total carbonate (including CO_3^{2-} , HCO_3^- and CaCO_3 (aq) of 10^{-3} M (60 mg/L as CO_3) in the liquid phase. The relevant equilibrium expressions are summarized in Table 9.8. The calculation procedure was as follows. First, the approximate value of the ionic strength (I) was evaluated by the following expression.

$$I = \frac{1}{2} \sum Z^2 C_i \quad (9.1)$$

I = ionic strength (M)

Z = charge on the ionic species

C_i = concentration of ionic species (M)

With the assumed ionic strength, the activity coefficients of the ionic species were then derived by the modified Davies' expression (Stumm and Morgan, 1981):

$$\log f = 1.82 \times 10^6 (ET)^{-3/2} Z^2 \left\{ \frac{\sqrt{I}}{1 + \sqrt{I}} - 0.31 \right\} \quad (9.2)$$

where

f = activity coefficient

E = dielectric constant for water

T = Absolute temperature ($^{\circ}\text{K}$)



TABLE 9.8

KEY LAKE PROJECT
MONITORING OF LAYERED URANIUM TAILINGS - PHASE I

MODEL EQUILIBRIUM CONSTANTS

MAJOR IONS		Log K	MOLYBDENUM	Log K
$\text{Ca SO}_4 \cdot 2\text{H}_2\text{O}(\text{s}) \rightleftharpoons \text{Ca}^{2+} + \text{SO}_4^{2-}$		-4.64	$\text{Ca MoO}_4(\text{s}) \rightleftharpoons \text{Ca}^{2+} + \text{MoO}_4^{2-}$	-8.00
$\text{Ca}^{2+} + \text{SO}_4^{2-} \rightleftharpoons \text{Ca SO}_4(\text{aq})$		2.31	$\text{MoO}_3(\text{s}) + \text{H}_2\text{O} \rightleftharpoons \text{H}_2\text{MoO}_4$	-12.10
$\text{Ca CO}_3(\text{am}) \rightleftharpoons \text{Ca}^{2+} + \text{CO}_3^{2-}$		-4.37	$\text{H}_2\text{MoO}_4 \rightleftharpoons \text{H}^+ + \text{H MoO}_4^-$	-4.24
$\text{Ca CO}_3(\text{calcite}) \rightleftharpoons \text{Ca}^{2+} + \text{CO}_3^{2-}$		-8.37	$\text{H}_2\text{MoO}_4 \rightleftharpoons 2\text{H}^+ + \text{MoO}_4^{2-}$	-12.88
$\text{Ca}^{2+} + \text{CO}_3^{2-} \rightleftharpoons \text{Ca CO}_3(\text{aq})$		3.20		
$\text{H}_2\text{CO}_3 \rightleftharpoons \text{H}^+ + \text{HCO}_3^-$		-6.46	NICKEL	Log K
$\text{H}_2\text{CO}_3 \rightleftharpoons 2\text{H}^+ + \text{CO}_3^{2-}$		-16.94	$\text{Ni(OH)}_2(\text{s}) + 2\text{H}^+ \rightleftharpoons \text{Ni}^{2+} + 2\text{H}_2\text{O}$	10.8
			$\text{Ni}^{2+} + \text{H}_2\text{O} \rightleftharpoons \text{NiOH}^+ + \text{H}^+$	-9.9
			$\text{Ni}^{2+} + 2\text{H}_2\text{O} \rightleftharpoons \text{Ni(OH)}_2(\text{aq}) + 2\text{H}^+$	-18.0
			$\text{Ni}^{2+} + 3\text{H}_2\text{O} \rightleftharpoons \text{Ni(OH)}_3^- + 3\text{H}^+$	-31.0
			$4\text{Ni}^{2+} + 4\text{H}_2\text{O} \rightleftharpoons \text{Ni}_4(\text{OH})_6^{4+} + 4\text{H}^+$	-27.7
			$\text{Ni}^{2+} + \text{SO}_4^{2-} \rightleftharpoons \text{Ni SO}_4(\text{aq})$	2.32
			URANIUM	Log K(0=0)
$\text{Ca}_3(\text{AsO}_4)_2(\text{s}) + 6\text{H}^+ \rightleftharpoons 3\text{Ca}^{2+} + 3\text{H}_3\text{AsO}_4$		23.25	$\text{UO}_3 \cdot \text{H}_2\text{O}(\text{s}) + 2\text{H}^+ \rightleftharpoons \text{UO}_2^{2+} + 2\text{H}_2\text{O}$	3.6
$(\text{CaO})_2\text{As}_2\text{O}_5(\text{s}) + 3\text{H}_2\text{O} + 4\text{H}^+ \rightleftharpoons 2\text{Ca}^{2+} + 2\text{H}_3\text{AsO}_4 + 2\text{H}_2\text{O}$		3.80	$\text{UO}_2\text{HAsO}_4(\text{s}) + 2\text{H}^+ \rightleftharpoons \text{UO}_2^{2+} + \text{H}_3\text{AsO}_4$	-1.3
$\text{H}_3\text{AsO}_4 \rightleftharpoons \text{H}^+ + \text{H}_2\text{AsO}_4^-$		-2.25	$\text{UO}_2\text{NaAsO}_4(\text{s}) + 3\text{H}^+ \rightleftharpoons \text{UO}_2^{2+} + \text{Na}^+ + \text{H}_3\text{AsO}_4$	-1.17
$\text{H}_3\text{AsO}_4 \rightleftharpoons 2\text{H}^+ + \text{HAsO}_4^{2-}$		-9.21	$\text{UO}_2\text{KAsO}_4(\text{s}) + 3\text{H}^+ \rightleftharpoons \text{UO}_2^{2+} + \text{K}^+ + \text{H}_3\text{AsO}_4$	-1.90
$\text{H}_3\text{AsO}_4 \rightleftharpoons 3\text{H}^+ + \text{AsO}_4^{3-}$		-20.71	$\text{UO}_2^{2+} + \text{H}_2\text{O} \rightleftharpoons \text{UO}_2(\text{OH})^+ + \text{H}^+$	-5.8
			$\text{UO}_2^{2+} + 2\text{H}_2\text{O} \rightleftharpoons \text{UO}_2(\text{OH})_2(\text{aq}) + 2\text{H}^+$	-12.1
			$\text{UO}_2^{2+} + \text{SO}_4^{2-} \rightleftharpoons \text{UO}_2\text{SO}_4(\text{aq})$	2.72
			$\text{UO}_2^{2+} + 2\text{SO}_4^{2-} \rightleftharpoons \text{UO}_2(\text{SO}_4)_2^{2-}$	4.13
			$\text{UO}_2^{2+} + \text{CO}_3^{2-} \rightleftharpoons \text{UO}_2\text{CO}_3(\text{aq})$	10.10
			$\text{UO}_2^{2+} + \text{XCO}_3^{2-} \rightleftharpoons \text{UO}_2(\text{CO}_3)_2^{2-}$	13.10

I = ionic strength
Z = ionic charge

The activity coefficients were used, in turn, to re-evaluate the equilibrium constants for the major ions and the concentrations of the various species were then calculated. The calculation procedure was iterative until convergence between ion concentrations and ionic strength was obtained. These calculations were performed for tailings porewater at pH = 10.43 and pH = 9.4. The results are summarized in Table 9.1.

The concentrations of "other ions" in Table 9.1 were calculated from an ionic charge balance:

$$(H^+) + 2(Ca^{2+}) + (I^+) = 2(SO_4^{2-}) + 2(CO_3^{2-}) + (HCO_3^-) + (OH^-) \quad (9.3)$$

() = concentration of species (M)

(I⁺) = concentration of other ions.

The concentrations of other (i.e. not directly modelled) ions were expressed as monovalent (Na⁺) equivalents due to the relative concentration prevalence of sodium (Na⁺) and potassium (K⁺) in the tailings porewater.

Comparing predicted concentrations of total dissolved calcium and total dissolved sulphate with observations, the predicted levels are within the range, (albeit near the lower observed values), in the tailings porewater. Undoubtedly, the dissolution of gypsum is the primary source of major ions and the ionic strength. An interesting outcome of the water quality modelling is that the tailings porewaters at present are apparently super-saturated with respect to calcite (CaCO₃), the saturation index being greater than 2.4 at pH values of 9.4 and above. This is significant, since the total dissolved carbonate of 10⁻³ M is essentially identical with measurements in the tailings porewater. A consequence of super saturation is that



TABLE 9.1
KEY LAKE PROJECT
MONITORING OF LAYERED URANIUM TAILINGS - PHASE I

GEOCHEMICAL MODEL PREDICTIONS FOR KEY LAKE TAILINGS POREWATER

<u>Dissolved Constituents</u>	<u>Concentration (M) at pH = 9.4</u>	<u>Concentration (M) at pH = 10.43</u>
HCO_3^-	7.79×10^{-4}	1.29×10^{-4}
CO_3^{2-}	4.80×10^{-5}	1.90×10^{-4}
CaCO_3 (aq)	1.73×10^{-4}	6.84×10^{-4}
TOTAL CARBONATE	10^{-3} (60 mg/L as CO_3)	10^{-3} (60 mg/L as CO_3)
Ca^{2+}	9.02×10^{-3}	9.06×10^{-3}
CaSO_4 (aq)	5.13×10^{-3}	5.13×10^{-3}
TOTAL CALCIUM	1.44×10^{-2} (590 mg/L)	1.40×10^{-2} (580 mg/L)
SO_4^{2-}	1.05×10^{-2}	1.00×10^{-2}
TOTAL SULPHATE	1.56×10^{-2} (1,500 mg/L)	1.51×10^{-2} (1,450 mg/L)
Other Ions (as Na^+ equivalent)	3.8×10^{-3}	2.39×10^{-3}
IONIC STRENGTH	4.1×10^{-2}	3.8×10^{-2}
Alkalinity (as mg/L CaCO_3)	61.05	93.85

Knight and Piessold Ltd.

CONSULTING ENGINEERS

the porewaters are not highly buffered at present and even a minimal increase in sulphate concentrations can cause a downward pH drift. Such a pH decline is evident in the leaching experiments in Table 8.7. At a pH of approximately 7.9, however, the waters become saturated with respect to calcite and pH decline below 7.9 is controlled by calcite dissolution equilibrium. These pH effects will be modelled in the following section.

9.2.1 pH Effects

As indicated in Section 9.2, the tailings porewaters are poorly buffered and small increases in sulphate concentrations may cause a pH decline. In this section, two scenarios in water quality are evaluated. In scenario I, the sulphate ion concentration (SO_4^{2-}) was increased by 10% as some metal sulphide oxidizes to sulphate. The carbonate concentration, however, was governed by calcite dissolution. In the second scenario, a 10% increase in total sulphate concentration was coupled with an increase in total carbonate content to 10^{-2} M in the porewater. Scenario II is believed to give the likely minimum pH in tailings porewater. The modelling methodology was as described in Section 9.2 except that the pH was used as a variable rather than a predetermined, constant value. The modelling results are summarized in Table 9.2. The predicted total sulphate concentrations of 1603 mg/L is essentially identical with observed maximum levels of 1620 mg/L in the leachate experiments. According to the two scenarios, the pH is expected to decline to the 6.7 - 7.5 range as a result of enhanced sulphate levels. Below a pH - 7.9, the dissolution of calcite is expected to become a controlling factor with regard to pH. As the pH declines, the buffering effect of dissolving calcite is of increasing significance. A total carbonate content of 10^{-2} M is the maximum value normally observed in groundwaters. Total carbonate concentrations of 10^{-2} M would



Association
of Consulting
Engineers
of Canada

Association
des Ingénieurs-
Conseils
du Canada

TABLE 9.2
KEY LAKE PROJECT
MONITORING OF LAYERED URANIUM TAILINGS - PHASE I

PREDICTED WATER QUALITY CHANGES
IN THE KEY LAKE TAILINGS POREWATER

<u>Chemical Constitutents</u>	<u>Scenario I</u>	<u>Scenario II</u>
HCO ₃ ⁻ (M)	2.07 x 10 ⁻³	9.99 x 10 ⁻³
CO ₃ ²⁻ (M)	1.76 x 10 ⁻⁶	2.33 x 10 ⁻⁶
CaCO ₃ (aq) (M)	5.51 x 10 ⁻⁶	7.94 x 10 ⁻⁶
TOTAL CARBONATE (M)	2.08 x 10 ⁻³	10 ⁻²
Ca ²⁺ (M)	9.24 x 10 ⁻³	7.81 x 10 ⁻³
CaSO ₄ (aq) (M)	5.13 x 10 ⁻³	5.13 x 10 ⁻³
TOTAL CALCIUM (M)	1.44 x 10 ⁻²	1.30 x 10 ⁻³
SO ₄ ²⁻ (M)	1.16 x 10 ⁻²	1.16 x 10 ⁻²
TOTAL SULPHATE (M)	1.67 x 10 ⁻²	1.67 x 10 ⁻²
pH	7.5	6.7
Alkalinity (as mg/L CaCO ₃)	103.5	500.0
OTHER IONS (as Na ⁺ equivalent) (M)	6.9 x 10 ⁻³	7.6 x 10 ⁻³
IONIC STRENGTH (M)	4.3 x 10 ⁻²	5.2 x 10 ⁻²

include extraneous sources of carbonate (i.e. in addition to calcite) such as decay of organic matters.

9.2.2 Ionic Strength

The ionic strength of solutions affects the solubility equilibrium, dissociation of acids and bases, as well as the formation of ligands (CaCO_3 (aq), for example) in the aqueous phase. These effects can be best expressed as single ion activity coefficients. Single ion activity coefficients are artificial entities in as much as they cannot be measured. However, they greatly simplify calculations of solubility products, dissociation, and ligand formation constants. The ionic strengths of tailings porewaters were calculated to range from 0.04 M to 0.05 M. The calculated activity coefficients are summarized below:

<u>Ion</u>	<u>Example</u>	<u>Activity Coefficients</u>
		<u>Calculated with Davis' Equation (Eq. 9.2)</u>
Uncharged	CaSO_4 (aq)	1.0
Monovalent	HCO_3^- , Na^+	0.84
Divalent	Ca^{2+} , CO_3^{2-}	0.50
Trivalent	Cr^{3+} , AsO_4^{3-}	0.21

The above activity coefficients were used to calculate the solubility of minor chemical constituents in the porewater.

9.2.3 Oxidation - Reduction Potential (Eh)

The primary value of the oxidation - reduction (Redox) potential is the assessment of the phase equilibria (EH - pH phase diagram) and



the direction (oxidation versus reduction) of chemical reactions. The positive Eh values in the tailings porewaters (220 mV to 280 mV at pH = 9.33 to pH = 10.43) indicate a potential for oxidation of reduced minerals such as arsenides and sulphides. The stable anionic species in the water phase are expected to be arsenates and sulphates. The oxidation states of metal ions depends on the species. For example, dissolved iron is expected to be as Fe^{3+} and chromium as Cr^{3+} and their ligands. Molybdenum, uranium and tungsten may be assumed to have an oxidation state of +6, molybdenum being present as molybdate (MoO_4^{-2}), while uranium as uranyl ion (UO_2^{2+}) and its complexes.

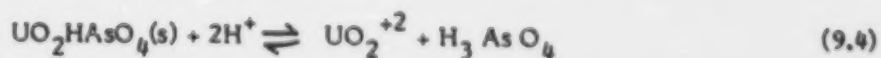
9.3 GEOCHEMICAL MODELS

To develop geochemical models for minor water quality constituents, thermodynamic equilibrium between solids phases and the aqueous phase was assumed. The modelling was performed at the chemical standard temperature of 25°C. Although porewaters would be below this temperature throughout most of the year, the thermodynamic data was either insufficient or too inexact to perform the necessary temperature adjustments.

As in case of major constituent modelling, the calculation procedure was kept simple. Only the most important ions and ligands were considered, since stability data on less significant ligands is often inaccurate (Smith and Martell, 1976). The purpose of the modelling attempts is to define trends and indicate problems, if any, with critical water quality constituents.

9.3.1 Overview of Equilibrium

The concept of chemical equilibrium can be best illustrated by the following example. Consider the following dissolution reactions:



The above reaction expresses the dissolution of solid uranyl arsenate in acidic media. The dissolution equilibrium of uranyl arsenate can be represented by the following:

$$K_{s,0} = \frac{(UO_2^{2+}) (H_3AsO_4)}{(H^+)^2} \quad (\text{below pH } 1.5) \quad (9.5)$$

where () = activity of the species.

The solubility constant $K_{s,0}$ refers to the activity products (zero ionic strength concentrations) of the chemical species. Correction for ionic strength is made to calculate actual concentrations. In the above example, the activity coefficient for the uranyl (UO_2^{2+}) ion is the only necessary correction, since the hydrogen ion is measured on the activity (i.e. $(H^+) = 10^{-pH}$) scale. The activity coefficient of unionized species (i.e. H_3AsO_4) is taken as unity. The activity coefficient for uranyl ion is calculated as a function of the ionic strength (Equation 9.2). Thus, in terms of concentrations, the equilibrium relationship becomes:

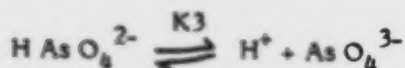
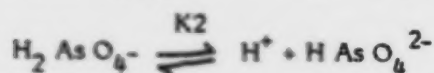
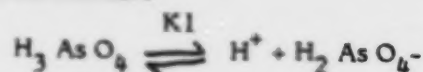
$$\frac{K_{s,0}}{f_{UO_2^{2+}}} = (10^{2pH}) (UO_2^{+2}) (H_3AsO_4) \quad (9.6)$$

where $k_{s,0}/f_{UO_2^{2+}}$ = solubility constant corrected for ionic strength.

() = concentration of species in mole/L

A second type of equilibrium expression takes into account the dissociation of acids (or bases). In the above example, hydrogen arsenate (H_3AsO_4) dissociates as illustrated below:

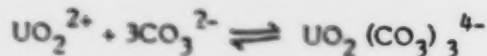
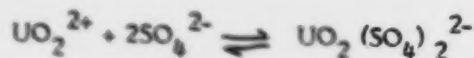
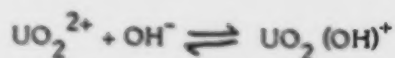




(9.7)

The equilibrium constants (K_1 , K_2 and K_3) are adjusted for a given ionic strength by the methodology outlined above. The use of these constants allows the assessment of arsenate speciation and the determination the total arsenate level at any pH, including alkaline pH values.

A third type of equilibrium involves the formation of ligands (i.e. ion pairs). For example, the uranyl ion will form complexes with hydroxyl ions, sulphate, and carbonate as follows:



The formation of ligands can be expressed by appropriate stability constants and after adjustments for ionic strength, may be used to calculate the total dissolved uranium concentration in the water.

In the present study, solubility, dissociation, and solubility constants were either obtained directly from published information (Smith and



Martell, 1978; Bjerrum et al, 1958), or calculated from thermodynamic data (Barner and Scheuman, 1978; Stumm and Morgan, 1981).

To standardize the procedure, the chemical modelling was performed under the following conditions in the aqueous phase:

Total Sulphate = 1,600 mg/L $(\text{SO}_4^{2-}) = 1.2 \times 10^{-2} \text{ M}$

Total Carbonate = 120 mg/L as CO_3 $(\text{CO}_3^{2-}) = \text{pH dependent}$

Total Calcium = 600 mg/L $(\text{Ca}^{2+}) = 9 \times 10^{-3} \text{ M}$

Ionic Strength = 0.04 M

pH = variable

Temperature: 25°C

9.3.2 Arsenic

The toxicity of arsenic to humans and its adverse effects on aquatic life has been long recognized. The toxicity and the chemistry of arsenic has been reviewed by Faust and Aly (1981). Stable forms in natural waters include trivalent (arsenites) and pentavalent (arsenate) species. Arsenates are several times less toxic than the more reduced forms. The pH and redox conditions in the Key Lake tailings porewater strongly favour arsenates. Phase diagrams of Eh versus pH indicate that an average Eh value of +250 mV, the trivalent forms would become prevalent at pH values below 5.0 only.

Measured concentrations of arsenic obtained during the Key Lake monitoring program and leaching studies are presented in Table 9.3.



TABLE 9.3

KEY LAKE PROJECT
MONITORING OF LAYERED URANIUM TAILINGS - PHASE I

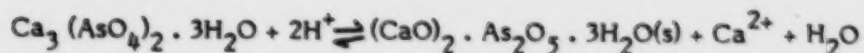
CONCENTRATION OF ARSENIC IN TAILINGS
INFLUENT, POREWATER AND LEACHATES

<u>Source</u>	<u>pH</u>	<u>As</u> <u>(mg/L)</u>	<u>Ca</u> <u>(mg/L)</u>
INFLUENT	12.1	.76	1050
	11.9	-	990
	11.8	-	
	9.3	-	530
	6.9	2.0	534
	6.4	2.2	520
EFFLUENT	11.3	-	780
	11.5	-	655
POREWATER	11.14	0.26	620
	10.43	.46	582
	9.98	.37	343
	9.48	2.2	620
	9.46	1.8	627
	9.33	1.6	582
LEACHING STUDIES	9.19	1.8	660
	7.8	2.6	610
	7.55	1.6	640
	6.68	2.08	615

Equilibrium conditions were probably achieved in the tailings pore-water and during the leaching tests. An obvious feature of these data is the rapid increase in arsenic concentration as the pH declines to about 10.0. Between pH values of approximately 8 to 10, the arsenic level is relatively constant at 2.2 mg/L. Below pH = 8.0, arsenic tends to increase again with decreasing pH.

To develop a model for arsenic solubility that is consistent with the data base, the following analysis is offered. Undoubtedly, at highly alkaline pH conditions (pH = 11), arsenic is deposited as calcium arsenate ($\text{Ca}_3 (\text{AsO}_4)_2 \cdot 3 \text{H}_2\text{O}$) in the tailings. The solubility of calcium arsenate in a high calcium environment governs dissolved arsenic in the water to a pH value of approximately 10.0. However, the solubility of calcium arsenate at near neutral pH values would be in excess of 100 mg/L (as As), that is two orders of magnitude above the measured concentrations. To explain the substantially lower observations, as well as the apparent concentration plateau at pH values of 8 to 10, it appears that the dissolution of calcium arsenate at pH 10 is incongruent. At lower pH values, arsenate re-precipitates as a secondary mineral, haidingerite ($(\text{CaO})_2 \cdot \text{As}_2\text{O}_5 \cdot 3\text{H}_2\text{O}$).

This transition in solid phases becomes evident in the following expression:



Equilibrium data for calcium orthoarsenate and haidingerite are summarized in Table 9.8.

The solubility constant for calcium arsenate was obtained from published data (Bjerrum et al., 1958), stability constants from Smith and Martell (1981), and haidingerite solubility was derived, in part,



from thermodynamic data (Barner and Scheuman, 1978), since no solubility constant was available from the literature. Using the equilibrium constants adjusted for the ionic strength, the effect of calcium concentrations and the pH on arsenic solubility can be derived as follows:

$$(\text{As})_T = \frac{10^{11.4}}{(\text{Ca}^{2+})^{1.5}} (10^{-3\text{pH}} + 10^{-(2\text{pH} + 2.17)} + 10^{-(\text{pH} + 8.91)} + 10^{-20.03})$$

Solid Phase: Calcium Arsenate for $\text{pH} > 10.3$

$$(\text{As})_T = \frac{10^{2.2}}{(\text{Ca}^{2+})} (10^{-2\text{pH}} + 10^{-(\text{pH} + 2.17)} + 10^{-8.91} + 10^{(\text{pH} - 20.03)})$$

Solid Phase: Haidingerite for $\text{pH} < 10.3$

The predicted concentrations of arsenic are given in Table 9.4. In spite of good agreement with observations (Table 9.3), the chemical model for haidingerite should be regarded as tentative until confirmed by more experimental work. It is noteworthy, however, that considerations of other solid phases for controlling arsenate levels (UO_2HAsO_4 , $\text{UO}_2\text{NaAsO}_4$, CrAsO_4 , etc.) were unsuccessful for predicting either the concentrations or the trend (i.e. the concentration plateau) in the water phase.

9.3.3 Molybdenum

At the prevailing conditions of pH and redox potential, molybdenum occurs as hexavalent molybdate in the Key Lake tailings porewater. At high pH values, molybdenum is present as calcium molybdate in the solid phase. As the pH declines, however, dissolved molybdenum



TABLE 9.4
KEY LAKE PROJECT
MONITORING OF LAYERED URANIUM TAILINGS - PHASE I
GEOCHEMICAL MODEL PREDICTIONS FOR ARSENIC
IN THE KEY LAKE TAILINGS POREWATER

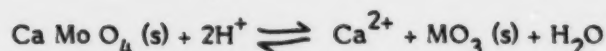
<u>pH</u>	Arsenate Concentration (as As)	
	<u>(Moles/L)</u>	<u>(mg/L)</u>
12	3.11×10^{-6}	0.233
11	6.36×10^{-6}	0.476
10.28	2.17×10^{-5}	1.62 --Solid phase Transition
10	2.17×10^{-5}	1.62
9	2.18×10^{-5}	1.63
8	2.29×10^{-5}	1.71
7	3.36×10^{-5}	2.53
6.7	4.54×10^{-5}	3.4 --Probable Minimum pH
6.0	1.41×10^{-4}	10.5

TABLE 9.5
KEY LAKE PROJECT
MONITORING OF LAYERED URANIUM TAILINGS - PHASE I
GEOCHEMICAL MODEL PREDICTIONS FOR MOLYBDENUM
IN THE KEY LAKE TAILINGS POREWATER

<u>pH</u>	<u>(Mole/L)</u>	Molybdate Concentration (as Mo)	
			<u>(mg/L)</u>
12	4.46×10^{-6}		0.43
11	4.43×10^{-6}		0.43
10	4.42×10^{-6}		0.42
9.44	4.40×10^{-6}		0.42
9	4.8×10^{-7}	$(4.89 \times 10^{-6})^*$	0.06 (0.47)*
8	1.07×10^{-8}	(9.06×10^{-6})	0.01 (0.87)
7	6.02×10^{-10}	(3.08×10^{-5})	0 (4.87)

* Values in parentheses represent no phase transition

may re-precipitate as molybdenum oxide $\text{MoO}_3(\text{s})$. This transition occurs at pH values of 9.44 or below and can be represented by the following equation:



The solubility and dissociation constants for molybdenum are given in Table 9.8. The constants were obtained from published data (Smith and Martell, 1978; Bjerrum et al., 1958) and the prediction of the phase transition is evident from the data base. The following models were obtained for predicting total dissolved molybdenum as the function of calcium concentration and pH:

$$(\text{Mo})_{\text{T}} = \frac{10^{4.78}}{(\text{Ca}^{2+})} (10^{-2\text{pH}} + 10^{-(\text{pH} + 4.16)} + 10^{-12.18})$$

$$\text{pH} > 9.44$$

Solid Phase: CaMoO_4

$$(\text{Mo})_{\text{T}} = 10^{-12.1} (1 + 10^{\text{pH} - 4.16} + 10^{2\text{pH} - 12.18})$$

$$\text{pH} < 9.44$$

Solid Phase: MoO_3

The predicted dissolved molybdenum in the tailings porewater is presented in Table 9.5. Comparing observations and predictions, the model predicts well at pH values above 9.0. Below pH = 9, however, the predicted concentrations (with MoO_3 as the solid phase) are substantially below the observed values. Thus, phase transition may not take place as predicted at pH = 9.44, or, the secondary precipitate is not crystalline MoO_3 . For this reason concentrations equilibrium with $\text{CaMoO}_3 (\text{s})$ at pH values below 9.44 are included in Table 9.5. These concentrations should be regarded as maximum predicted concentrations in the tailings porewater.



9.3.4 Nickel

The stable solid phase for nickel under alkaline entities is $\text{Ni}(\text{OH})_2$. The equilibrium equations are given in Table 9.8 and the derived solubility relationship is as follows:

$$(\text{Ni})_T = 10^{11.12} 10^{-2\text{pH}} + 10^{-(\text{pH} + 10.15)} + 10^{\text{pH} - 31.35} + 10^{-18.25}$$

The predicted concentrations are given in Table 9.6.

At pH values below 8.0, however, oxides and hydroxides of nickel are unstable. In the presence of high sulphate content, dissolved nickel would re-precipitate as nickel hydroxy sulphate having a general formula $m\text{Ni}(\text{OH})_2 \cdot n\text{NiSO}_4$. This phenomenon is not unlike the formation of jarosites ($\text{FeK}(\text{SO}_4)_2 \cdot 2\text{Fe}(\text{OH})_3$) from ferric hydroxides ($\text{Fe}(\text{OH})_3$) at high sulphate and low pH conditions. The solubility product (K_{so}) of nickel hydroxy sulphate, expressed as:

$$\frac{\text{Ni}(\text{OH})}{n+m} \frac{2m(\text{SO}_4)}{n+m}$$

is in the order of 10^{-13} (Smith and Martell, 1976). The data on nickel concentrations in Key Lake porewater indicate no strong pH dependency. This would suggest $\text{Ni}(\text{OH})_2 \cdot \text{NiSO}_4$ as a possible solid phase and equilibrium nickel concentrations in the porewater as follows:

$$(\text{Ni})_T = \frac{10^{1.45 - \text{pH}}}{(\text{SO}_4^{2-})^{0.5}} \text{ for pH } \geq 8.0 (1 + 10^{(\text{pH} - 10.15)} + 10^{(3\text{pH} - 31.35)} + 10^{(2\text{pH} - 18.25)})$$

The predicted concentrations of nickel are summarized in Table 9.6. Although concentrations measured in porewaters and leachates at



TABLE 9.6

KEY LAKE PROJECT
MONITORING OF LAYERED URANIUM TAILINGS - PHASE I

GEOCHEMICAL MODEL PREDICTIONS FOR NICKEL
IN KEY LAKE TAILINGS POREWATER

<u>pH</u>	Concentrations	
	<u>(Mole/L)</u>	<u>(mg/L)</u>
12	8×10^{-8}	0.005
11	7.5×10^{-8}	0.005
10	1.26×10^{-7}	0.008
9	2.15×10^{-7}	0.013
8	1.33×10^{-5}	0.784
7	2.17×10^{-5}	1.51
6.7	5.13×10^{-5}	3.01
6.0	2.57×10^{-4}	15.11

near neutral pH values are usually below the predicted concentrations, equilibrium values may reach 1-10 mg/L nickel at pH values of 6.5-7.0.

9.3.5 Uranium

The Redox potential in the tailings porewater favour the presence of U(VI) ligands in the liquid phase. The solubility data stability constants for relevant U(VI) minerals are summarized in Table 9.8. The data were derived from publications by Bjerrum et al. (1958), Langmuir (1978), and Lemire and Tremaine (1980). At alkaline pH conditions ($\text{pH} > 8.0$), uranium oxide ($\text{UO}_3 \cdot \text{H}_2\text{O}$) is the relevant solid phase. At pH values below 8.0, however, the solubilities of uranyl arsenates appear to control the dissolved uranium content in the porewater.

Considering the measured sodium (Na^+) and potassium (K^+) concentrations in porewater and leach water (Table 8.4), the stable mineral is most likely the potassium salt: $\text{UO}_2 \cdot \text{KAsO}_4$ (s). The solubility of this mineral was evaluated with potassium concentrations ranging from 5 mg/L (1.28×10^{-4} M) to 15 mg/L (3.84×10^{-4} M). The calculation procedure was as follows. First the concentration of the uranyl ion (UO_2^{2+}) was calculated from solubility data adjusted to an ionic strength of 0.04 M from the following equations:

For $\text{pH} \geq 8.0$

$$(\text{UO}_2^{2+}) = 10^{5.6-2\text{pH}}$$

For $\text{pH} \leq 8.0$

$$(\text{UO}_2^{2+}) = \frac{10^{-1.45}}{(\text{As})_T + (\text{K}^+)} (10^{-3\text{pH}} + 10^{-(2\text{pH} + 2.17)} + 10^{-(\text{pH} + 8.91)} + 10^{-20.03})$$



Then, the total uranium concentration was determined by inclusion of hydroxo ($\text{UO}_2(\text{OH})^+$, $\text{UO}_2(\text{OH})_2(\text{aq})$), sulphato ($\text{UO}_2\text{SO}_4(\text{aq})$, $\text{UO}_2(\text{SO}_4)_2^{2-}$) and carbonato ($\text{UO}_2\text{CO}_3(\text{aq})$, $\text{UO}_2(\text{CO}_3)_2^{2-}$) ligands:

$$(\text{U(VI)})_T = (\text{UO}_2^{2+}) \left\{ 1 + 10^{\text{pH}-5.57} + 10^{2\text{pH}-11.8} + 10^{9.5} (\text{CO}_3^{2-}) + 10^{14.5} (\text{CO}_3^{2-})^2 + 10^{2.12} (\text{SO}_4^{2-}) + 10^{3.85} (\text{SO}_4^{2-})^2 \right\}$$

The predictions of total dissolved uranium in the tailings porewater are summarized in Table 9.7. The uranium concentrations were derived for total carbonate (H_2CO_3 , HCO_3^- , CO_3^{2-} , and $\text{CaCO}_3(\text{aq})$) of 2×10^{-3} M, sulphate ion concentrations (SO_4^{2-}) of 1.2×10^{-2} M and calcium ion (Ca^{2+}) concentrations of 9×10^{-3} M. The influence of dissolved arsenate on uranium concentrations is evident at pH values below 8.0. The decrease of dissolved uranium with increasing pH ($\text{pH} \geq 8.0$) is due to the constraint on the total carbonate level. At predicted steady state pH values of 6.7 to 7.5, the dissolved uranium concentrations are predicted to be 0.3 to 1.0 mg/L U(VI).

References

- Barner, E., and Scheuman, R.V. (1978): "Handbook of the Thermochemical Data", J. Wiley and Sons, New York, N.Y., U.S.A.
- Bjerrum, J., Schwarzenbach, G., and Sillen, L.G., (1958): "Stability Constants, Part II, Inorganic Ligands" Special Pub. No. 7, London: The Chemical Society, Burlington House, W.I.
- Faust, S.D., and Aly, O.M., (1981): "Chemistry of Natural Waters", Ann Arbor Science, Ann Arbor, Mich., U.S.A.
- Smith, R.M., and Martell A.E., (1976): "Critical Stability Constants, Volume IV, Inorganic Complexes" Plenum Press, New York, N.Y., U.S.A.



TABLE 9.7

KEY LAKE PROJECT
MONITORING OF LAYERED URANIUM TAILINGS - PHASE I

PREDICTED TOTAL URANIUM CONCENTRATIONS IN TAILINGS POREWATER

pH	<u>TOTAL ARSENATE</u>		<u>CARBONATE</u>		<u>TOTAL URANIUM CONCENTRATION (as U)</u>			
	(As As)	(Moles/L)	(CO ₃ ²⁻)	(Moles/L)	Potassium = 1.28×10^{-4} M	(mg/L)	Potassium = 3.84×10^{-4} M	(mg/L)
11	6.36×10^{-6}		4.20×10^{-4}					
10	2.17×10^{-5}		3.12×10^{-4}		1.26×10^{-6}	0.30	1.26×10^{-6}	0.3
9	2.18×10^{-5}		8.76×10^{-5}		1.51×10^{-6}	0.36	1.51×10^{-6}	0.36
8	2.29×10^{-5}		1.05×10^{-5}		3.27×10^{-6}	0.78	3.27×10^{-6}	0.78
7.0	3.36×10^{-5}		8.80×10^{-7}		6.69×10^{-6}	1.59	6.67×10^{-6}	1.59
6.7	4.54×10^{-5}		3.70×10^{-7}		5.06×10^{-6}	1.20	1.71×10^{-6}	0.41
6.0	1.41×10^{-5}		3.18×10^{-8}		3.99×10^{-6}	0.93	1.33×10^{-6}	0.32
					1.71×10^{-6}	0.41	5.77×10^{-7}	0.14

Knight and Piésold Ltd.

CONSULTING ENGINEERS

Stumm, W., and Morgan, J.J., (1981): "Aquatic Chemistry" John Wiley and Sons, New York, N.Y., U.S.A.

Langmuir, D. (1978): "Uranium Solution - Mineral Equilibria at Low Temperatures with Applications to Sedimentary Ore Deposits" *Geochimica et Cosmochimica Acta*, Vol. 42, 547-569.

Lemire, R.J. and Tremaine, P.R. (1980): "Uranium and Plutonium Equilibria in Aqueous Solutions to 200°C". *J. Chem. and Eng. Data*, Vol. 25, 361-370.



Association
of Consulting
Engineers
of Canada

Association
des Ingénieurs-
Conseils
du Canada

SECTION 10.0 - SEEPAGE MODELLING

10.1 INTRODUCTION

Detailed seepage analyses have been carried out to simulate the distribution and movement of moisture within the tailings mass and to refine estimates of total seepage through the tailings both during operation and after decommissioning. The overall objective was to provide order of magnitude estimates of seepage, so that the potential implications of any geochemical activity can be viewed in a realistic perspective. The analyses considered movement of potential seepage through the tailings mass only and did not consider any of the interaction of the seepage once in the underdrainage system with the external seals of the facility.

The seepage analyses were carried out using the transient finite element computer program TRASEE. This program was developed by the Department of Civil Engineering at the University of Saskatchewan to model seepage through saturated and unsaturated porous media.

The governing equation in the program is a non-linear differential equation based on Darcy's Law for flow through porous media, in which the coefficient of permeability of the material decreases as pore water suctions increase. Transient boundary conditions can be input to model the varying conditions at the tailings surface and calculation of the flux across any boundary within the finite element mesh can be made.

The seepage modelling has been carried out in two phases corresponding to the operational phase and to the long term after decommissioning. The operational phase investigated moisture movement and seepage during a hypothetical 14 years of operation with a gradually increasing depth of tailings. The long term phase investigated moisture movement and seepage after decommissioning and construction of a surface seal. Details of the analyses are given in the following sections.



10.2 OPERATIONAL PHASE

10.2.1 General

Seepage analyses of the operational phase of the tailings facility consisted of two models considering vertical seepage only, and a third model to investigate any effects of anisotropy. The vertical seepage model was analyzed for two sets of material parameters and surface boundary conditions corresponding to a "best estimate" (Case 1) and a "worst case" (Case 2). These models were intended to simulate conditions occurring within the tailings at locations remote from the main embankment. The anisotropic model consisted of a two dimensional mesh, with one sloping side drainage boundary to simulate conditions adjacent to the main embankment and used the Case 1 input parameters. For anisotropic conditions the assumed coefficient of permeability in the horizontal direction was one order of magnitude greater than in the vertical direction to simulate observed laminations and segregation within each layer.

A total of 14 computer runs were carried out for each of the three models, with one run corresponding to one year of operation. The total production of tailings for each year was added to the top of the mesh at the start of that year, with the tailings deposit being built up in 14 increments of 1.2 metres. Nodal head values at the end of any one year were used as input data for the subsequent run.

Boundary conditions at the tailings surface were varied over the year to simulate tailings deposition and meteorological conditions occurring at the site. These conditions were based on a year starting on November 1, and were made up of an initial 6 month period of zero flux, simulating frozen conditions during winter, followed by alternating cycles of evaporation, and rainfall and tailings deposition.



Periods of rainfall or deposition were simulated by imposing a zero pore water pressure condition on the surface nodes of the mesh, while periods of evaporation were simulated by applying a moisture flux from the surface corresponding to potential evaporation. A schematic diagram illustrating the surface boundary conditions is given on Figure 10.1.

10.2.2 Vertical Seepage Model, Case 1

Input data for the "best estimate" Case 1 model are summarized as follows:

- Each tailings layer was added in a drained and fully saturated condition with zero pore water pressures.
- Evaporation from the surface of the tailings was based on potential lake evaporation for the site, with no reduction after the tailings become unsaturated, as indicated by the observations described in Section 5.8.5. However a maximum suction pressure of 10 m of water was imposed.
- The function relating the coefficient of permeability to suction pressure was as derived from the Tempe Cell tests, and is as shown on Figure 5.16. A limitation on the decrease in permeability at large suction levels was imposed to reduce instability and convergence problems with the program.

In this analysis extremely low coefficients of permeability developed very rapidly within the tailings. Frequently the surface of the tailings acted as a seal against infiltration and moisture movement occurred very slowly within the tailings.



MONITORING OF LAYERED URANIUM TAILINGS - PHASE I

OPERATIONAL PHASE SURFACE BOUNDARY CONDITIONS FOR TYPICAL YEAR VERTICAL SEEPAGE MODEL AND ANISOTROPIC MODEL

For pore pressure profiles at
times A, B, C and D see
Figure 10.2

(D)

(C)

(B)

(A)

Time period when evaporation
is occurring at indicated
flux (typ.)

Evaporation flux
($\text{m}^3/\text{m}^2/\text{s}$)

Surface frozen, zero
surface flux

Time period with surface saturated
at zero pore pressure, allowing
infiltration to occur (typ.)

Nov. | Dec. | Jan. | Feb. | Mar. | April | May | June | July | Aug. | Sept. | Oct. | 12

TIME (MONTHS)

Profiles of pore water pressure over the full depth of tailings at 4 time intervals during each of years 2, 8 and 14 of operation are shown on Figure 10.2. The selected time intervals are shown in relation to surface boundary conditions on Figure 10.1. The profiles indicate a fairly dynamic situation with downward movement of moisture occurring across thin horizons with very large gradients. These horizons represent wetting fronts with small quantities of water under positive pressure overriding zones of partially saturated tailings. Within the zones on either side of each wetting front very little moisture movement takes place as the pore water pressure distributions are close to hydrostatic.

Seepage quantities from the base of the tailings were extremely small and showed a progressive decrease during operation. The resulting total quantity of seepage from the full tailings area is plotted on Figure 10.3 and summarized below:

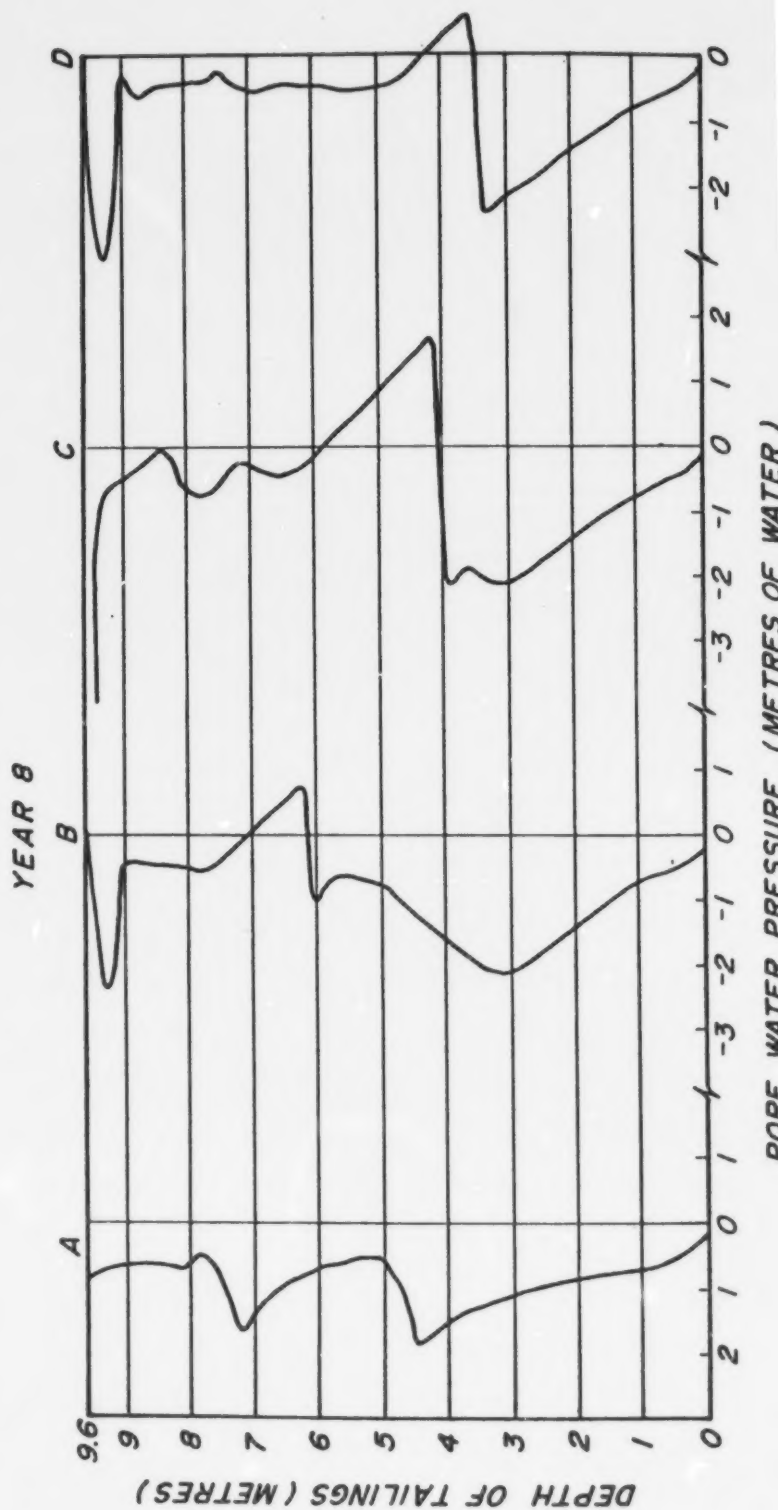
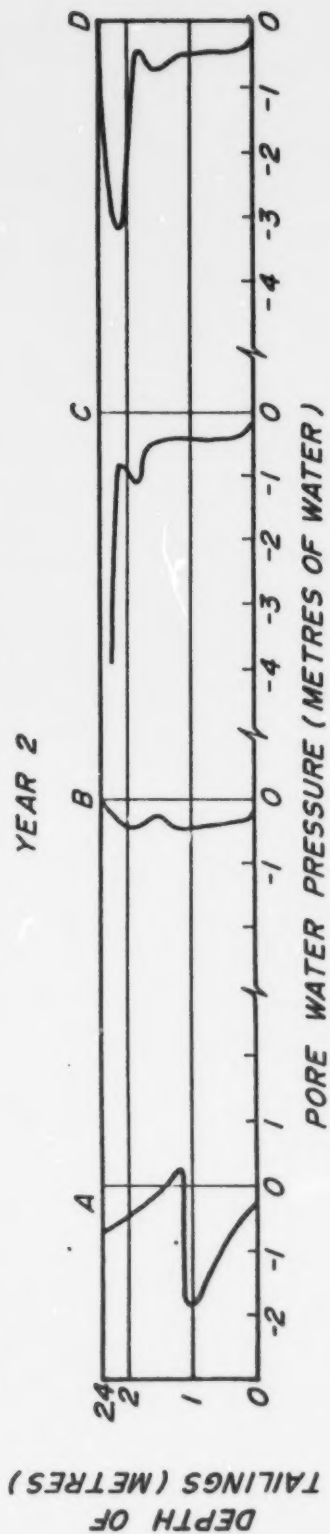
<u>Year</u>	<u>Seepage</u> <u>Rate</u> ($\text{m}^3/\text{m}^2/\text{s}$)	<u>Total Seepage</u> (Full tailings area) (m^3/yr)
1	1.97×10^{-10}	1860
14	4.75×10^{-12}	45

One implication of the above is that after one or two years of operation the anticipated seepage rate from the base of the tailings will be less than the detection limit of the underdrainage system, since the seepage rates are less than the coefficient of permeability of the till bentonite underseal over which any seepage must flow to reach the collector pipes.

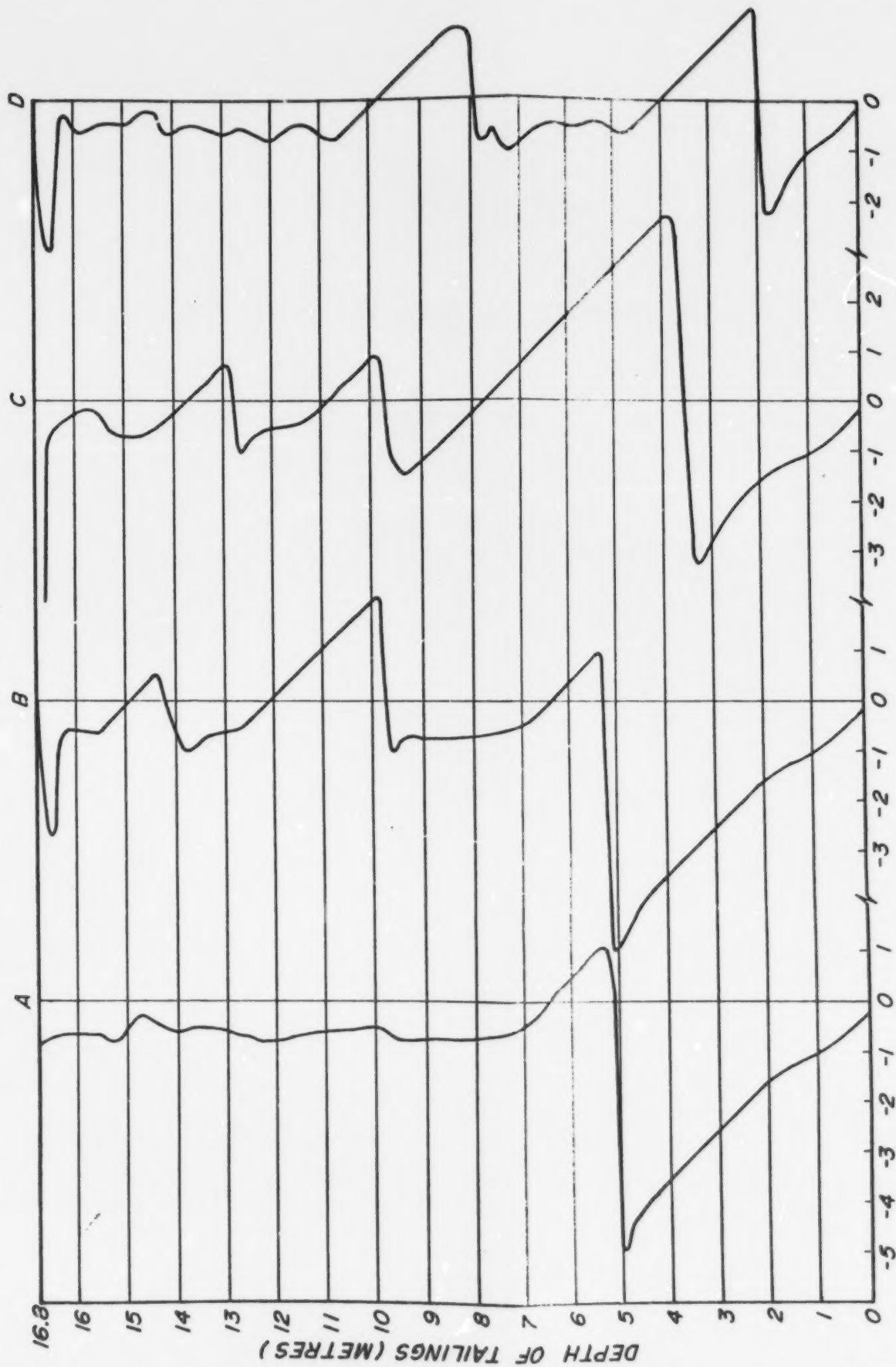


MONITORING OF LAYERED URANIUM TAILINGS - PHASE I

OPERATING PHASE
PORE WATER PRESSURE PROFILES
CASE I - VERTICAL SEEPAGE MODEL



YEAR 14



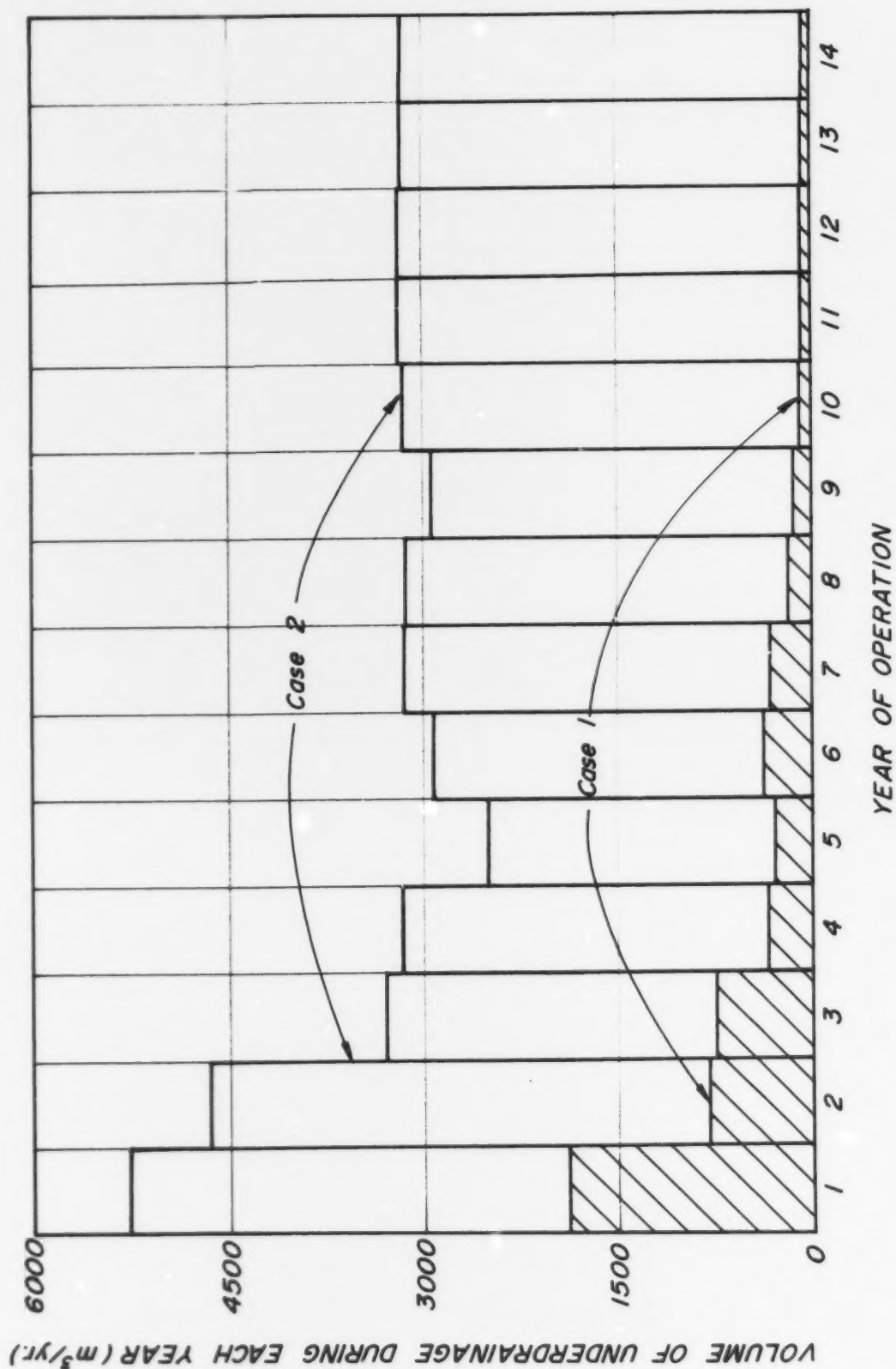
NOTE: PORE WATER PRESSURE (METRES OF WATER)

1. For boundary condition at time of profiles A, B, C and D, see Figure 10.1.

FIGURE 10.2

MONITORING OF LAYERED URANIUM TAILINGS - PHASE 1

OPERATIONAL PHASE SEEPAGE INTO UNDERDRAIN CASES 1 AND 2 VERTICAL SEEPAGE MODEL



10.2.3 Vertical Seepage Model, Case 2

Input data for the "worst case" Case 2 model differed from the Case 1 in the followings ways:

- Each tailings layer was added to simulate a slurry with a resulting pore pressure distribution within the layer equal to the full slurry density.
- Evaporation rates from the tailings surface were reduced to 80 percent of the Case 1 evaporation rates to allow for the inherent difficulty of modelling evaporation from a tailings surface in the laboratory.
- The function relating the coefficient of permeability to suction pressure was further limited to reduce the effect on permeability at large suction pressures as shown on Figure 5.16.

In general, the Case 2 analyses resulted in greater movement of moisture through the system, with relatively uniform hydraulic gradients and a continuous downward migration of moisture.

Seepage from the base of the tailings was greater than in the Case 1 analyses but the same trends towards a significant reduction in seepage quantity with time were observed. Specific values of total seepage for each year of operation are shown on Figure 10.3 and summarized as follows:

<u>Year</u>	<u>Seepage</u>	<u>Total Seepage</u>
	<u>Rate</u> ($\text{m}^3/\text{m}^2/\text{s}$)	<u>(Full tailings area)</u> (m^3/yr)
1	5.5×10^{-10}	5200
3 and onwards	3.2×10^{-10}	3000



These seepage rates roughly correspond to the limits of detection of the underdrainage system.

10.2.4 Anisotropic Model

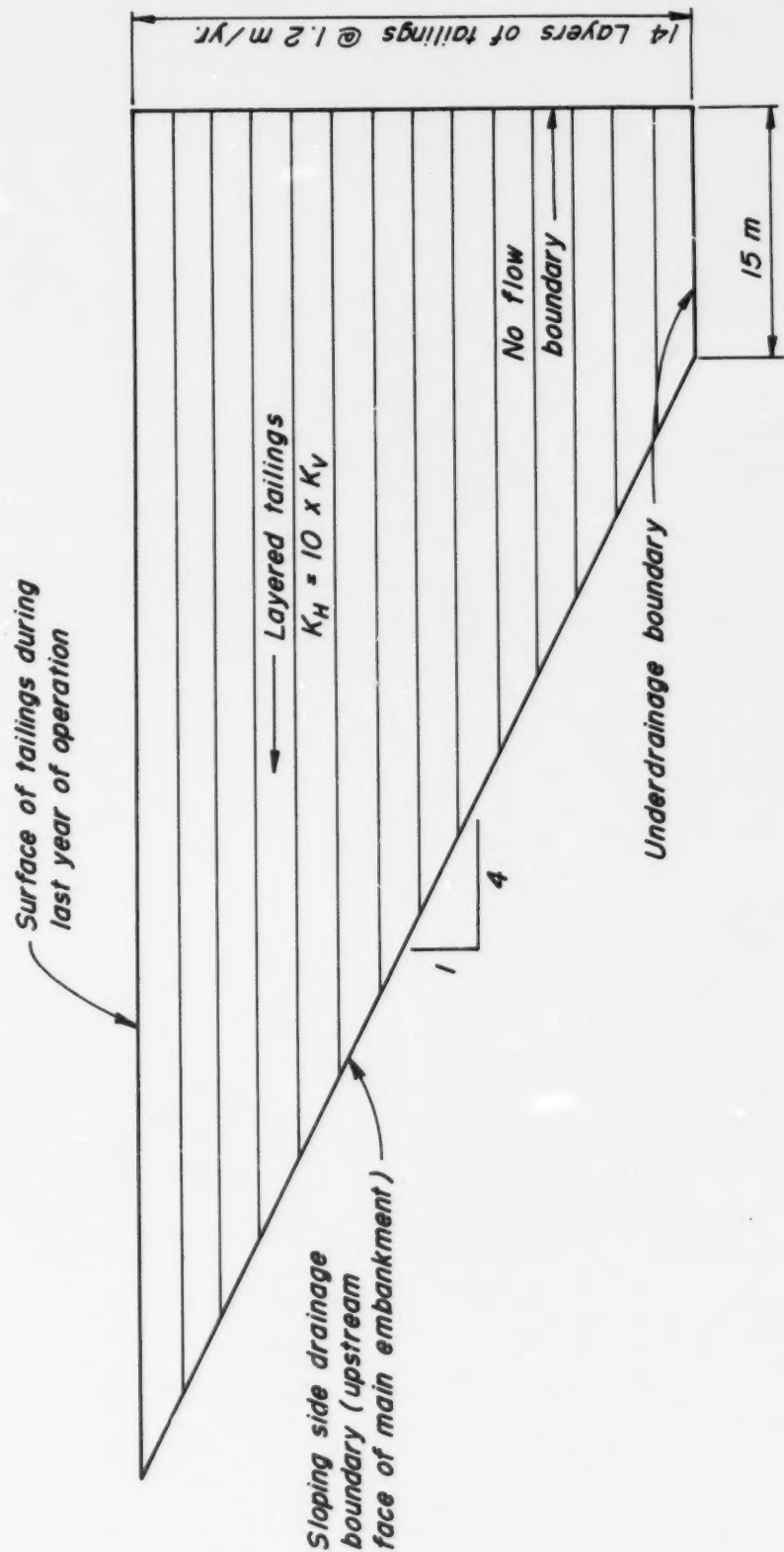
The anisotropic model was analyzed with the same tailings parameters and surface boundary conditions as the Case 1 vertical seepage model, with horizontal coefficients of permeability increased by a factor of 10. A schematic diagram of the anisotropic model is shown on Figure 10.4 at the end of 14 years of operation.

During the computer analyses of the anisotropic model some difficulty was encountered in achieving converged solutions for the problem. The difficulty arose as a result of the complicated mesh being used, together with the extreme permeability function for the tailings and the effects of anisotropy. For the program to converge, large tolerances were set on the iterative procedure, which resulted in less accurate and occasionally erratic solutions. However, some general trends observed in the analyses were as follows:

- Seepage from the base of the tailings was maintained at rates slightly less than for the Case 1 model on a unit area basis.
- Seepage into the sloping filter increased during the initial years of operation, as the build-up of tailings reduced the downward moisture movement and enhanced horizontal flow.
- Seepage into the sloping filter was generally less than 13 cubic metres per year for the entire main embankment.



MONITORING OF LAYERED URANIUM TAILINGS - PHASE I
SCHEMATIC DIAGRAM OF MESH GEOMETRY FOR ANISOTROPIC CASE
SHOWN DURING LAST YEAR OF OPERATIONAL PHASE



NOTE:
 Vertical scale exaggerated to 2 times
 horizontal scale

On the basis of these analyses it can be supposed that the influence of anisotropy is limited at Key Lake due to the already extremely low coefficients of permeability of the unsaturated tailings.

10.3 LONG TERM PHASE

10.3.1 General

Modelling of the long term phase of the Key Lake tailings storage facility was carried out as an extension of the operational phase vertical seepage models. Both models consisted of a vertical column of tailings with a surface seal generally corresponding to current best practice technology

The surface seal used in the modelling consisted of a 300 mm layer of free-draining sand underlying a 300 mm seal of low permeability soil/bentonite. The purpose of the sand is to act as a capillary break to prevent the upward migration of contaminated seepage, and to prevent any large negative pore water pressures developed within the tailings from drawing moisture out of the soil/bentonite layer.

Permeability functions for the sand and soil/bentonite were obtained from Tempe Cell tests carried out at the University of Saskatchewan on fine sand and Regina Clay samples, and from actual permeability testing of the proposed seal materials carried out during construction of the facility.

Surface boundary conditions for each long term model consisted of three scenarios in which repeated cycles of infiltration into the surface seal were imposed for 20, 30 and 100 percent of the time. Between cycles of infiltration a surface condition of zero flux was imposed. These three scenarios correspond to a realistic case of infiltration during approximately 20 percent of each year, a slightly



more onerous case for infiltration for 30 percent of the time, and a worst case for continuous infiltration, to provide an upper bound for long term seepage estimates.

In practise, the surface seal will also contain a coarse drainage layer above the soil/bentonite seal, with additional soil for plant growth above this. A detailed analysis of actual flux rates through the seal was beyond the scope of this study.

Both long term models used the nodal head values achieved at the end of the operational phase as the initial condition for each analysis. Analyses were carried out for approximately 300 years after decommissioning, at which point steady state conditions were observed.

10.3.2 Vertical Seepage Model, Case 1

Long term seepage rates from the tailings for the Case 1 analyses, using the "best estimate" of material parameters, are shown on Figure 10.5. Significant results of the analyses are as follows:

- Seepage from the tailings is very small for all three scenarios of surface infiltration, being less than $10 \text{ m}^3/\text{yr}$ for the entire facility 50 years after decommissioning.
- Steady state conditions were achieved throughout the tailings after 250 years for infiltration for 20 and 30 percent of the time, and after 60 years for infiltration 100 percent of the time.

10.3.3 Vertical Seepage Model, Case 2

Long term seepage rates from the tailings for the Case 2 analyses,

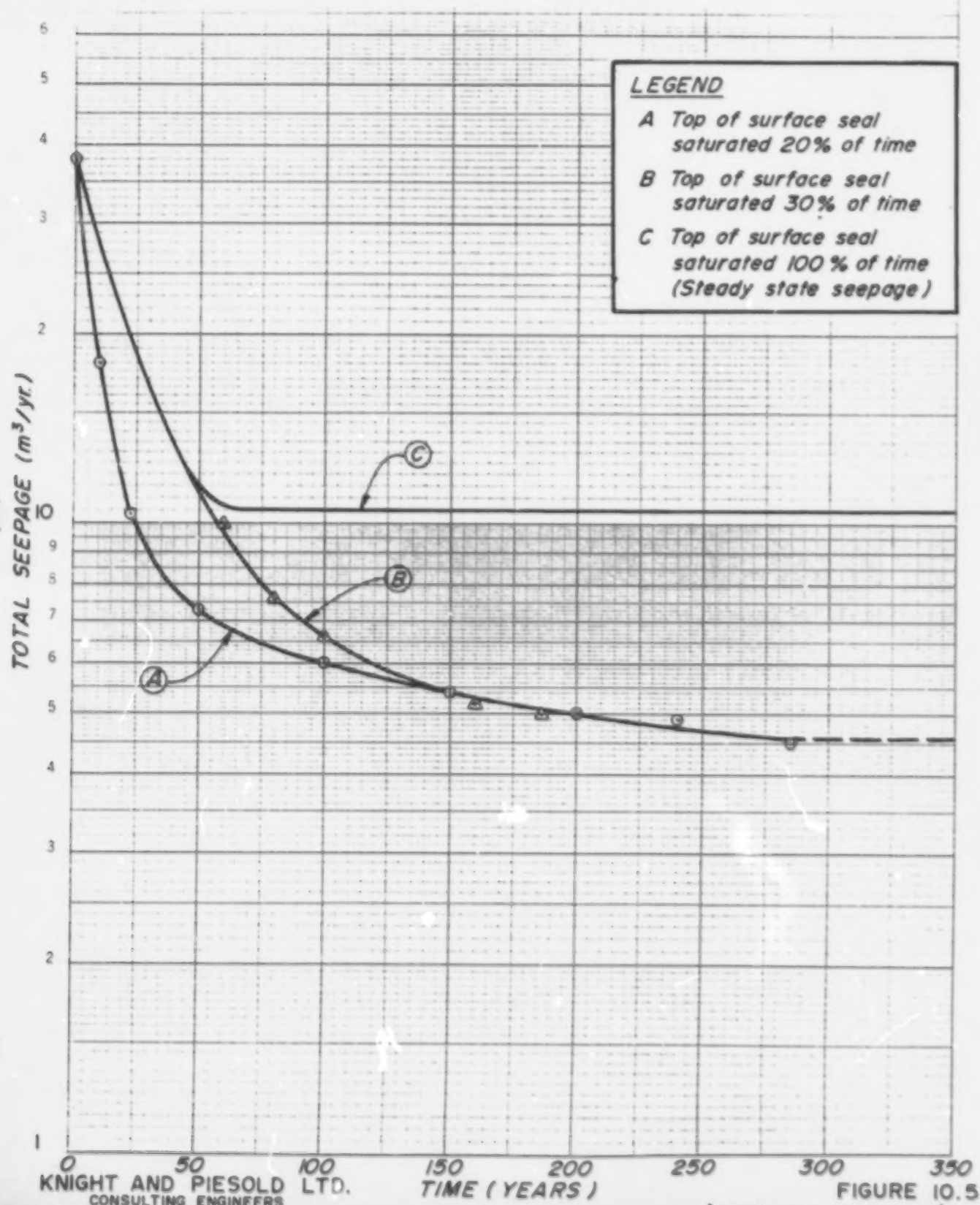


MONITORING OF LAYERED URANIUM TAILINGS - PHASE I

LONG TERM PHASE

SEEPAGE INTO UNDERDRAIN

CASE I. VERTICAL SEEPAGE MODEL.

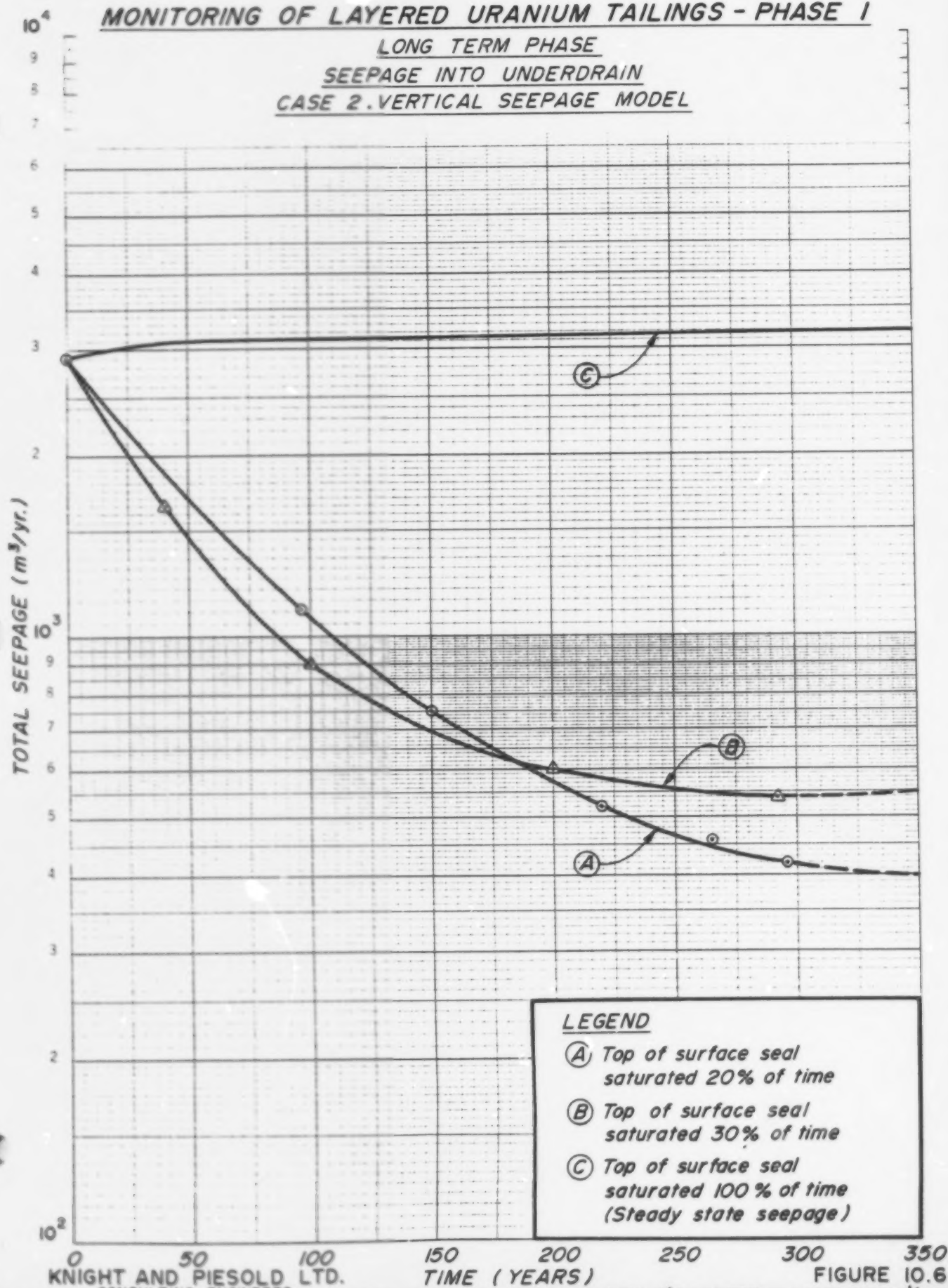


MONITORING OF LAYERED URANIUM TAILINGS - PHASE I

LONG TERM PHASE

SEEPAGE INTO UNDERDRAIN

CASE 2. VERTICAL SEEPAGE MODEL



using worst case material parameters, are shown on Figure 10.6. The results indicate the following points:

- Seepage from the tailings for all three scenarios of surface infiltration was approximately two orders of magnitude greater than for the Case 1 analyses. Total seepage was $3000 \text{ m}^3/\text{yr}$ for the worst case surface condition of continuous infiltration.
- A more realistic estimate of total seepage using these material parameters is in the order to $500 \text{ m}^3/\text{yr}$.

10.4 SUMMARY OF SEEPAGE MODELLING

The seepage modelling carried out using the University of Saskatchewan transient finite element computer program permitted some reasonable modelling of actual moisture movements within a sub-aerial tailings deposit. These have indicated that the tailings material becomes the major barrier to significant moisture movement once partial saturation occurs and suction pressures are developed, due to the very significant resulting decrease in permeability. Provision of the underdrainage system at Key Lake ensures that these conditions prevail.

The analyses for the operational phase of the tailings facility indicate the following range of values for the total seepage from the base of the tailings:

	Total Seepage (m^3/yr)	
	Year 1	Year 14
Best Estimate	1860	45
Worst Case	5200	3000

These seepage rates are all at or below the limits of detection of the underseal. For comparison, a conventional wet disposal system with an



Knight and Piésold Ltd.
CONSULTING ENGINEERS

equivalent area, that relies on a 1 m thick bottom liner with a coefficient of permeability of 1×10^{-8} m/s for seepage containment (AECB Licensing Document 23D), could theoretically result in total seepage through the liner of $95,000 \text{ m}^3/\text{yr}$ in the first year of operation and this would increase as the depth of ponded water increased.

Estimates of long term seepage have been made using simplifying assumptions for a surface seal. These have resulted in the following order of magnitude estimates:

Long Term Seepage Rate

Realistic Estimate	less than $10 \text{ m}^3/\text{yr}$
Worst Case (Ponded water over entire surface at all times)	$3000 \text{ m}^3/\text{yr}$

These estimates indicate negligible long term seepage and support the original design objectives for the tailings facility.



SECTION 11.0 - RECOMMENDED SCOPE OF WORK FOR PHASE II

11.1 OBJECTIVES

One of the principle objectives of Phase I of the study has been to obtain detailed information on the physical behaviour of the tailings solids during operation. Observations and data accumulation have been carried out from August 1984 to March 1985, predominantly over the winter period. A major objective of the proposed Phase II of the study is therefore to continue physical monitoring of the tailings to complete at least a full year of observations at the test sites.

The Phase I studies have produced a good understanding of the chemistry of the tailings solids and potential seepage rates. In particular, estimates have been made for both the long term seepage flow and quality. The major question remaining to be answered is "what is the long term consequence of this seepage?" The major data requirements to answer these questions are an estimate of the groundwater flows and characteristics which dilute the seepage; and distribution coefficients of the sub-surface soils and rock which will retard the rate of migration.

As a first estimate it would appear that with the estimated low seepage flows, the consequences of long term seepages on a potential receptor would be minimal. However, some preliminary modelling is proposed for a 1,000-10,000 year period to demonstrate this aspect.

A further objective will be to integrate and compare the results and predictions obtained from the monitoring study with routine measurements carried out by Key Lake personnel on the overall monitoring systems for the facility. Specifically these would include flow rates and water quality from



the supernatant and underdrainage collector systems, and regional groundwater piezometer levels and groundwater quality.

11.2 SCOPE OF WORK

The following scope of work is proposed:

- (i) Continuation of field monitoring and data accumulation.
 - Reactivate data logging systems at Site A, with some modifications to sensors and data logger.
 - Carry out site visits on a bi-monthly basis for data extraction and physical readings of moisture/density.
 - Collect sample of seepage water for laboratory testing under (iii) below.
- (ii) Application of field data.
 - Analyse field data to obtain further information on tailings density, seepage rates, pore pressures, surface evaporation, precipitation run-off, etc.
 - Re-assess water balance on the basis of a full year of observed readings.
- (iii) Assessment of long term implications of potential seepage.
 - Assemble data on groundwater flows and quality in the vicinity of the tailings facility.



- Undertake some laboratory K_D testing using seepage collected from the test site and actual underlying materials (e.g. sand filter blanket, till/bentonite underseal, till, sandstone). The seepage pH is typically 7.0 and should be adjusted to 5.0 for some test work.
 - Using estimated seepage rates and seepage quality estimates from Phase I, conduct a contaminant transport model.
 - Obtain environmental concentrations at receptor and assess dose and non-radiological effects using a probabilistic modelling approach (Developed by Senes for the NUTP).
- (iv) Integration of monitoring study results with observed overall performance.
- Integrate any relevant data from KLMC field monitoring in (ii) and (iii) above.
 - Compare results of predicted seepage rates and water quality with that observed at main collector sump.
 - Compare results of contaminant transport modelling with actual groundwater piezometer monitoring data.
 - Comment on relevance of study findings to observed overall performance of the tailings facility.
- (v) Improve understanding of tailings mineralogy.
- Carry out thermogravimetric analyses on a range of tailings



samples to establish the extent of non free water losses occurring below drying temperatures. Establish a meaningful procedure for determining tailings moisture content.

- Investigate tailings material to identify the minerals which contain the major Nickel and Arsenic concentrations.

11.3 SCHEDULE FOR PHASE II

It is essential to recommence field monitoring and data accumulation prior to thawing of the tailings so that detailed observations can be made over this period. This represents the most critical aspect of the study and all equipment should be in place and reactivated by the end of April at the latest.

The following general schedule for the scope of work is proposed:

	<u>1985</u>
Reactivation of data accumulation	end April
Site visits	April, June, August, October
Decommission monitoring installations	October
Application of field data	September-November
Laboratory K_D testing	July
Contaminant transport modelling	August-September
Comparisons with KLMC monitoring	September-November
Probabilistic modelling of long-term effects	October-November
Draft report	end November
Final report	end December



APPENDIX AI

**TERMS OF REFERENCE
ORIGINAL STATEMENT OF WORK**

STATEMENT OF WORK

Key Lake Layered Tailings Monitoring

OBJECTIVE

To obtain information on detailed behaviour of bulk-neutralized, mineralogically-complex uranium tailings at the Key Lake operations, in order to provide long-term behaviour prediction of these tailings deposited by the sub-aerial method.

BACKGROUND

A new high-grade uranium mining and milling operation commenced operation in Northern Saskatchewan in October 1983. A unique waste disposal system has been installed that is designed to meet disposal objectives while operating, and in the long-term, after mining and milling is completed. This is the first uranium tailings waste management facility to go into operation that contains close-out design, and is the first facility to receive wastes from the recently discovered high-grade and mineralogically complex ore bodies in Saskatchewan. These deposits represent the most significant sources of uranium in Canada and possibly in the world.

The Key Lake waste management facility is extensively engineered and the external monitoring systems represent the current state of technology. Because the waste materials and the containment system are new, little is known about their nature and behaviour in the long-term in the harsh Northern Saskatchewan environment. The monitoring systems are external to the tailings management facility; the performance and behaviour of the tailings can only be inferred in the very long-term after decommissioning. An opportunity exists to determine the nature and behaviour of the tailings

during placement, and to generate information required for long-term predictions. Field tests will be undertaken which will last up to 18 months, starting June 1984.

TEST PROGRAM AND ANALYSES - PHASE I

JUNE 1984 - FEBRUARY 1985

1. Set up two monitoring sites in the Key Lake tailings storage facility. The general location of the site are Site Nos. 1 and No. 3 as shown in Figure 2. Site No. 1 will be instrumented as shown in Figure 3. Site No. 3 will be instrumented for monthly observations only.
2. For Site No. 1, determine the following on a continuous or intermittent basis as appropriate:
 - (a) Vertical temperature profile.
 - (b) Piezometer levels.
 - (c) Seepage flow - automatically collected.
 - (d) Atmospheric conditions.
3. For Site No. 1, determine the following monthly:
 - (a) Moisture and density (neutron probe).
 - (b) Chemical analyses of seepage collection (10 elements). The contractor must submit for approval to the Scientific Authority plans for ensuring that sample integrity is maintained in the collection system and that suspended solids are removed before analytical determinations are undertaken.

- (c) Chemical analyses of runoff. Because the tailings storage facility may be used to store excess process water during the operation of the Phase I test program, methods of sample collection will need to be devised. The possible construction of a sand berm in the tailings basin may facilitate this collection. As for seepage samples, integrity of samples must be maintained, and the relationship of the sample contents to the test site must be firmly established. It will be recognized that variations in ore treated and operation of the waste treatment plant may affect the chemistry of the runoff from the general facility.
 - (d) Direct radiation, gamma. Determination of gamma radiation by hand-held instrumentation one metre from the tailings surface is required.
 - (e) Radon flux. The method of measurement will be by track-etch detector.
 - (f) Ice/snow cover when applicable.
 - (g) Semi-quantitative analyses of surface crust, if present.
 - (h) Make field observations on the flow of and build-up of tailings at the test site and relate to the general facility.
4. For Site No. 3, determine the following monthly:
- (a) Moisture and density (neutron probe).
 - (b) Temperature profile.
 - (c) Ice/snow cover when applicable, gamma radiation and radon flux.

- (d) Make field observations of physical properties of tailings such as surface crusts, cracking, surface strength, etc. (qualitative observations only are required).

5. In October 1984:

- (a) Extract 3 cores from each test site by thin-wall tube sampler and transport to licensed physical and chemical testing laboratory by best means to preserve chemical and physical integrity of extracted cores.
- (b) Determine the following physical properties of extracted cores: water content, density, shear strength, permeability, porosity and grain size.
- (c) From Site No. 1, determine the chemical constituents of moisture in the cores. It is recognized that the moisture content of Site No. 1 cores may be low and chemical analyses will be determined on a priority basis:
 - (i) Priority A (highest) - plasma scan for metallic elements, Ra^{226} , pH, Eh.
 - (ii) Priority B - U, Ca, Fe, SO_4 .
 - (iii) Priority C - Th^{230} , Pb^{210} , Po^{210} .
- (d) From Site No. 3, determine the chemical constituents of moisture in the cores. It is expected that moisture content will be higher. However, priorities as in 5(c) above are to be followed.

- (e) Determine the chemical content of the solids of each core - U, Ni, As, Mo, Co, Th²³⁰, Ra²²⁶, Pb²¹⁰, Po²¹⁰, Mg, Ca, Fe, Al, Si, SO₄, CO₃.
 - (f) Determine the water leachable constituents from one core from each location, (chemical analyses as in (c)). The laboratory method for determining the constituents shall be submitted for approval by the Scientific Authority.
 - (g) Determine the cation exchange capacity of the material from one core from each location.
 - (h) Conduct mineralogical identification of the solids in a representative core from each location. Special techniques such as X-ray diffraction, SEM energy dispersive fluorescence, quantimet analyses and mineral microscopy may be required.
- 6. Analyse hydrological data from field and laboratory tests. From the analysis of the data, derive functional relationships for tailings deposition, water movement and balance. The level of effort for derivation of the functional relationship is expected to not exceed 20 person-days.
 - 7. From the field and laboratory observations, and from published geochemical and thermodynamic data, adapt and apply a geochemical model to describe the long-term chemical character of the tailings. For Phase I, this geochemical model should be restricted to the tailings themselves, excluding the interaction of the tailings with the actual or theoretical tailings impoundment materials.
 - 8. Produce a draft report for review containing observations, data and analyses, derivation of functional relationships and results of the

geochemical model development. Provide details of the Phase II monitoring requirement (if applicable).

SPECIAL CONSIDERATIONS FOR THIS WORK

1. The Key Lake Tailings Storage Facility is an active operational site and field conditions may necessitate that the specified field work be altered, suspended or cancelled. Every reasonable effort must be made to minimize the impact of the program on the operation of the Key Lake uranium mine facilities.
2. Laboratory analyses and tests must be conducted within qualified Quality Assurance Programs that are approved by the Scientific Authority.
3. All normal procedures and regulatory approvals concerning the handling of radioactive materials must be strictly observed.
4. The level of effort requirements for the development of the geochemical model is to be about 40 person days. Recognized geochemical modelling expertise is required in the project team.

PHASE II (Brief Description Only)

A continuation of the field program may be implemented, depending on the results of the Phase I program, a review by the National Uranium Tailings Program, and on permission of the operating company, Key Lake Mining Corporation. Included in the Phase II test program may be a study of the interaction of the tailings with impoundment soils.

Phase II field tests would be completed by October 1985. At that time, salvageable equipment would be decontaminated and removed from the

field. Should Phase II not proceed, equipment removal will be accomplished in May 1985. Phase I proposal will include a plan and cost estimate for equipment removal.

PLEASE NOTE THAT PHASE II IS NOT PART OF THE REQUIREMENT FOR THIS REQUISITION.

APPENDIX AII

**TERMS OF REFERENCE
ADDITIONAL WORK AND CONTRACT AMENDMENTS**

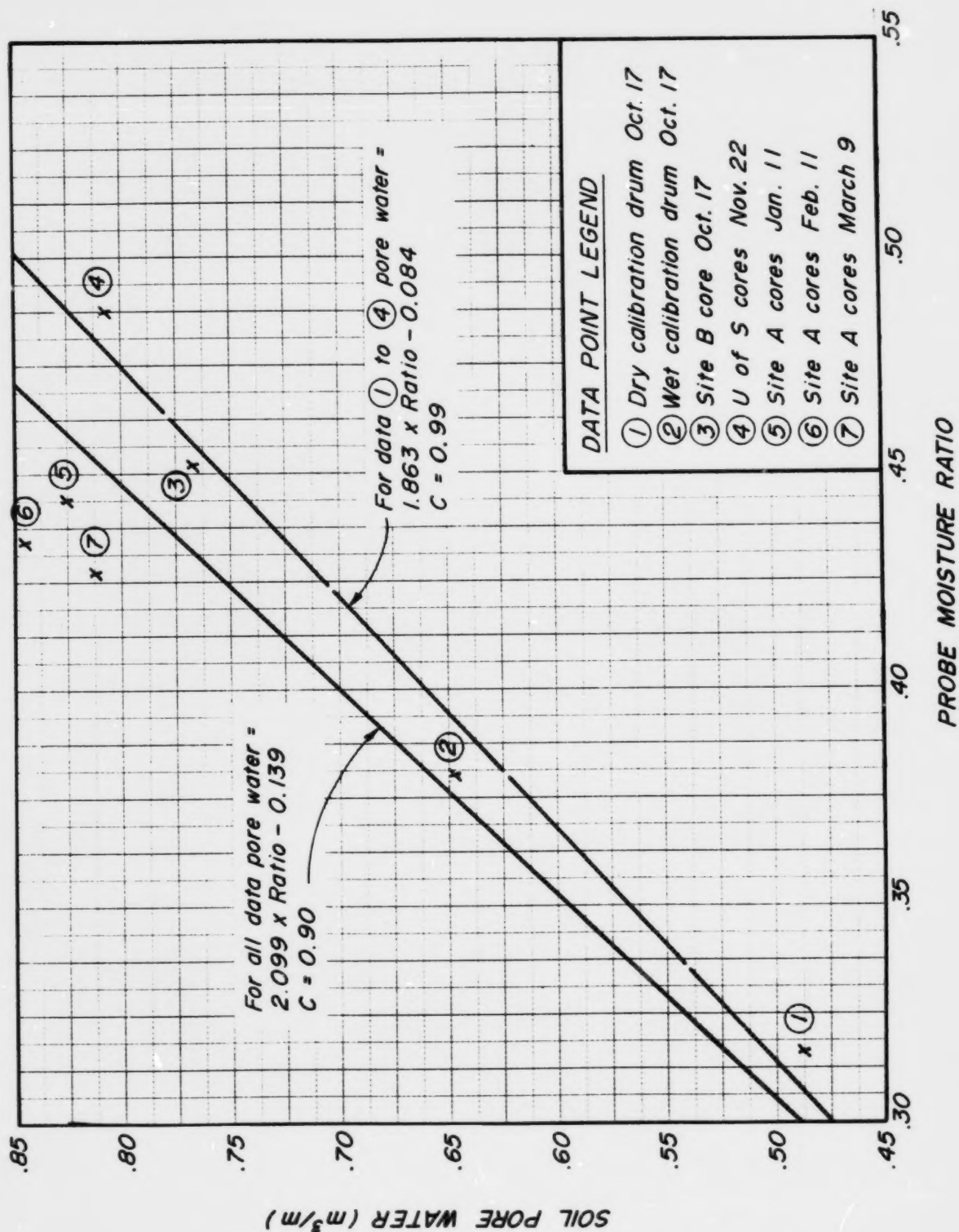
ADDITIONAL WORK AND CONTRACT AMENDMENTS

1. Additional Visits February and March with all possible Items measured as per Items 2, 3 and 4 in Statement of Work. Recommend composite feed sample with determination of percent solids and flow rate. This information may be available from KLMC. Retain solids for possible future use. Winter deposition observations required, rejecting situations which can be rejected as non-typical of operation.
2. Additional chemical analyses. All priorities plus organics. Organics in solids previously collected in cores.
3. Additional seepage analyses. Carry out transient saturated/unsaturated finite element seepage analyses to determine on-going seepage from tailings.
4. Determine, based on field measurements, the water balance of the whole facility. It is realized because of absence of whole year data, estimates will be required.
5. Determine ice penetration and predict residual ice, short and long term.
6. Expand geochemical modelling to include use of previous pilot scale data. Additional meeting VCVR required by sub-contractor.
7. Administrative. Change Draft Report February 21 to March 29. Change Final Report March 29 to April 30. Copies of Final Report 25.

APPENDIX B

DATA TABLES

MONITORING OF LAYERED URANIUM TAILINGS - PHASE I **CALIBRATION CURVES FOR CPN MOISTURE PROBE**



MONITORING OF LAYERED URANIUM TAILINGS - PHASE I

CALIBRATION CURVES FOR CPN DENSITY PROBE

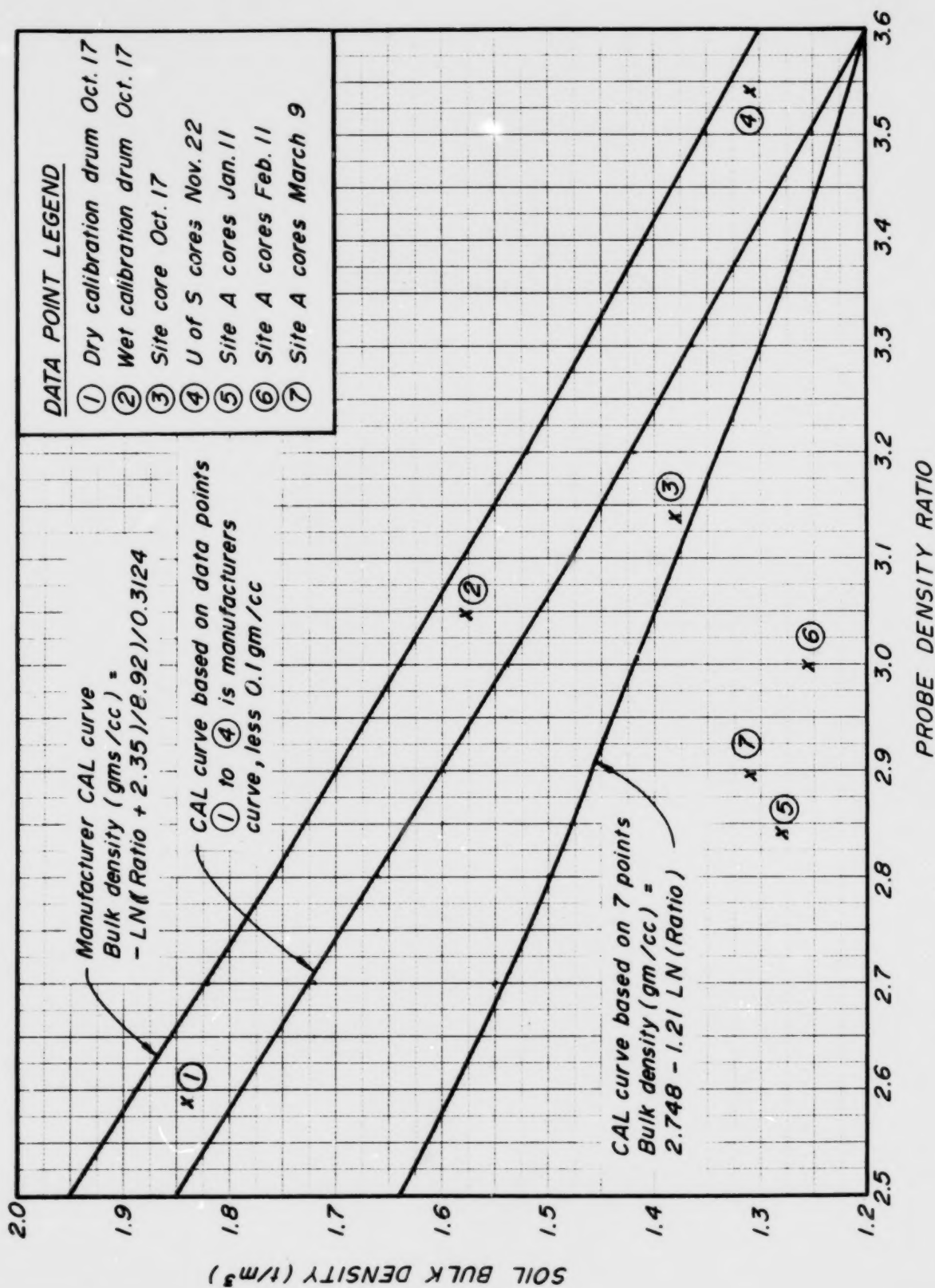
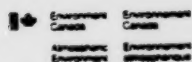


TABLE B1



CLIMATOLOGICAL STATION REPORT

STATION KEY LAKE

406 3755-360 SA

Time of observation 8:00 a.m. 6:30 p.m.



PROVINCE SASK

Observer E KRAHN K SANTO

MONTH AUGUST

19 84

Observer		E KRAHN		KANTO		MONTH												
DAY OF MONTH	TIME OF OBSERVATION	TEMPERATURE (°C)					PRECIPITATION					TIMES OF PRECIPITATION (Calendar Day)		Depth of Snow on Ground (cm)	Weather (Calendar Day)			REMARKS
		Maximum		Minimum		AFTER RESET	Rain		Snow		Total For Day	Begin	Ended		Thunderstorm	Freezing Rain	Hail	
		Observed	For Day	Observed	For Day		Measured	For Day	Measured	For Day								
1	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	
1	8:00			14.5		20.0											OVERCAST IN SMOKE	
1	11:00	29.0	29.0	20.0	14.5	28.0	-										OVERCAST IN SMOKE	
1	14:00	27.5		12.5		20.5	-										CLEAR WITH SMOKE	
1	17:00	32.0	32.0	20.5	12.5	31.0	-										1/10 SMOKEY	
1	20:00	31.0		20.5		24.0	-										2/10 SMOKEY	
1	23:00	32.0	32.0	24.0	20.5	31.0	-	1.2			1.2						1/10 SMOKEY	
2	8:00	31.0		15.0		22.0	1.2										9/10 CC	
2	11:00	31.0		21.5	15.0	29.5	-										3/10 CC	
2	14:00	29.5		15.0		20.0	-										5/10 CC	
2	17:00	30.5	30.5	20.0	15.0	29.0	-	10.8			10.8						5/10 CC	
2	20:00	28.5		17.5		18.0	10.8										5/10 CC	
2	23:00	27.5	27.5	19.0	17.5	19.5	-	T			T						OVERCAST	
3	8:00	19.5		15.5		16.0	T										OVERCAST w RAIN	
3	11:00	22.0	22.0	13.0	13.0	13.0	2.0	4.8			4.8						OVERCAST w RAIN	
3	14:00	15.0		12.5		15.0	2.8										9/10	
3	17:00	20.5	20.5	15.0	12.5	20.5	-	1.4			1.4						10/10	
3	20:00	20.0		14.0		14.5	1.4										14/10	
3	23:00	21.5	21.5	14.0	14.0	21.0	-										CLEAR	
4	8:00	21.0		16.0		19.0	-										CLEAR	
4	11:00	28.0	28.0	16.0	16.0	25.5	-										CLEAR	
4	14:00	25.0		10.5		15.5	-										3/10 9/10	
4	17:00	22.5	22.5	14.5	10.5	22.0	-										CLEAR	
4	20:00	22.0		10.5		20.0	-										9/10	
4	23:00	27.0	27.0	20.0	10.5	25.0	4.0				4.0						9/10	
13	8:00	24.5		15.5		17.0	4.0										9/10	
13	11:00	24.5	24.5	17.0	15.5	19.5	0.4	7.6			7.6						19/10 RAINING	
13	14:00	19.0		11.0		11.5	7.2										15/10 RAINING	
13	17:00	15.0	15.0	10.5	10.5	14.0	0.2	0.2			0.2						9/10	
13	20:00	14.0		4.0		10.5	T										OVERCAST	
13	23:00	16.5	16.5	10.5	4.0	15.5	0.4	0.4			0.4						CC 5/10	
14	8:00	15.5		11.0		14.0	-										CC 3/10	
14	11:00	20.5	20.5	14.0	11.0	18.5	-										CC 2/10	
14	14:00	18.5		9.5		16.0	-										CLEAR	
14	17:00	25.5	25.5	16.0	9.5	24.5	-										CC 2/10	
14	20:00	24.5		9.5		16.0	-										CC 2/10	
14	23:00	26.0	26.0	16.0	9.5	24.5	T	0.4			0.4						CC 8/10	
15	8:00	24.5		15.0		18.0	0.4										CC 8/10	
15	11:00	22.0	22.0	17.0	15.0	21.0	-										CC 2/10	
15	14:00	21.0		11.0		14.5	-										CC 9/10	
15	17:00	19.0	19.0	13.5	11.0	15.0	3.6	7.4			7.4						OVERCAST	
15	20:00	15.0		10.5		11.5	5.8										CC 3/10	
21	8:00	18.0	18.0	11.0	10.5	17.5	-										CLEAR	
21	11:00	17.5		10.0		14.0	-										CC 2/10	
21	14:00	25.0	25.0	14.0	10.0	24.0	-										CC 4/10	
21	17:00	24.0		14.0		16.5	-										CC 6/10	
21	20:00	26.5	26.5	16.5	14.0	25.5	-										CLEAR	
21	23:00	25.5		14.0		15.0	-										CC 5/10	
22	8:00	22.0	22.0	13.0	14.0	20.0	-										CC 7/10	
22	11:00	20.0		10.5		15.0	-										CC 4/10	
22	14:00	23.0	23.0	14.5	10.5	22.5	-	1.2			1.2						CC 4/10	
22	17:00	22.5		13.0		14.0	1.2										OVERCAST	
22	20:00	23.0	23.0	13.5	13.0	22.0	T	T			T						2/10	
22	23:00	22.0		9.0		14.5	-										5/10	
23	8:00	22.5	22.5	9.0	9.0	21.0	-	4.0			4.0						9/10	
23	11:00	21.0		9.0		10.0	4.0										6/10	
23	14:00	10.0	10.0	3.5	3.5	4.0	1.1	3.5			3.5						OVERCAST, RAIN	
23	17:00	5.0		2.5		5.0	3.4										OVERCAST, RAIN	
23	20:00	9.0	9.0	4.5	4.5	3.0	12.5	14.1			14.1						OVERCAST, RAIN	
23	23:00	8.5		4.5		7.0	1.6										3/10 DRIZZLE	
24	8:00	11.0	11.0	4.5	4.5	9.5	T	T			T						3/10	
24	11:00	10.0		5.0		4.5	-										OVERCAST	
24	14:00	4.5	4.5	4.0	4.0	4.5	-										9/10 CC	
24	17:00	0.5		4.0		4.5	T											
Total no. of days with																		
SUM		687.0		356.0		61.0		61.0		TEMPERATURE EXTREMES		Mean Max. 22.16		Mean Min. 11.48				
MEANS		22.16		11.48						Maximum 32.0 Date AUG 23		Minimum -2.5 Date AUG 29		Mean 16.82				

TEMPERATURE

Mean Max. 22.16

Maximum 32.0 Date AUG 23 Mean Min. 11.48

Minimum -2.5 Date AUG 29 Mean 11.48

59 0453-2304 14/771

TABLE B2

1+ ☐ ☐ ☐ ☐

METRIC
CLIMATOLOGICAL STATION REPORT

STATION _____

Time of observation 8:00 a.m. 6:30 p.m.PROVINCE SASK.Observer KENT SAUTER, E. KRAHNMONTH SEPTEMBER19 94

DAY OF MONTH	TIME OF OBSERVATION	TEMPERATURE (°C)					PRECIPITATION					TIME OF PRECIPITATION (Calendar Day)		Weather (Calendar Day)	REMARKS																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																												
		Maximum		Minimum		AFTER RISE	Rain		Snow		Total Per Day	Begin	End																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																														
		Observed	For Day	Observed	For Day		Measured	For Day	Measured	For Day																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																	
																3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																											
1	8:00			1.5		5.5																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																					

TABLE B3

14 Temperature
Celsius
Precipitation
mm

METRIC
CLIMATOLOGICAL STATION REPORT

STATION Key LakeTime of observation 8:00 a.m. 6:30 p.m.PROVINCE Sask.Observer Eldon Kraba & Nat SaultMONTH October19 54

DAY OF MONTH	TIME OF OBSERVATION	TEMPERATURE (°C)					PRECIPITATION					TIMES OF PRECIPITATION (CLOUDY DAY)				REMARKS
		Maximum		Minimum		AFTER RESET	Rain		Snow		Total For Day	Begin	End	Depth of Snow on Ground		
		Observed	For Day	Observed	For Day		Observed	For Day	Observed	For Day						
1	8:00	9.0	9.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0					AM - CC 1/2	
2	8:00	0.0	0.0	-1.0	-1.0	0.0	0.0	0.0	0.0	0.0					PM - overcast	
3	8:00	5.5	5.5	-0.5	-0.5	0.0	0.0	0.0	0.0	0.0					AM - "	
4	8:00	2.0	2.0	-3.5	-3.5	0.0	0.0	0.0	0.0	0.0					PM - CC 1/2	
5	8:00	-6.0	-6.0	-4.0	-4.0	0.0	0.0	0.0	0.0	0.0					PM - overcast	
6	8:00	-1.5	-1.5	-5.0	-5.0	0.0	0.0	0.0	0.0	0.0					AM - overcast	
7	8:00	0.5	0.5	-3.5	-3.5	0.0	0.0	0.0	0.0	0.0					PM - overcast	
8	8:00	9.0	9.0	-1.0	-1.0	0.0	0.0	0.0	0.0	0.0					AM - overcast	
9	8:00	12.0	12.0	2.5	2.5	0.0	0.0	0.0	0.0	0.0					PM - CC 1/2	
10	8:00	9.0	9.0	-1.0	-1.0	0.0	0.0	0.0	0.0	0.0					AM - CC 1/2	
11	8:00	5.5	5.5	0.5	0.5	0.0	0.0	0.0	0.0	0.0					PM - CC 1/2	
12	8:00	16.0	16.0	6.5	6.5	0.0	0.0	0.0	0.0	0.0					AM - CC 1/2	
13	8:00	15.5	15.5	6.0	6.0	0.0	0.0	0.0	0.0	0.0					PM - CC 1/2	
14	8:00	21.5	21.5	6.0	6.0	0.0	0.0	0.0	0.0	0.0					AM - CC 1/2	
15	8:00	18.0	18.0	3.0	3.0	0.0	0.0	0.0	0.0	0.0					PM - clear	
16	8:00	22.5	22.5	8.5	8.5	0.0	0.0	0.0	0.0	0.0					AM - clear	
17	8:00	21.5	21.5	9.0	9.0	0.0	0.0	0.0	0.0	0.0					PM - clear	
18	8:00	21.0	21.0	6.5	6.5	0.0	0.0	0.0	0.0	0.0					AM - clear	
19	8:00	15.5	15.5	9.0	9.0	0.0	0.0	0.0	0.0	0.0					PM - overcast	
20	8:00	13.0	13.0	10.0	10.0	0.0	0.0	0.0	0.0	0.0					AM - overcast	
21	8:00	11.5	11.5	9.5	9.5	0.0	0.0	0.0	0.0	0.0					PM - overcast	
22	8:00	12.5	12.5	10.0	10.0	0.0	0.0	0.0	0.0	0.0					AM - overcast	
23	8:00	11.5	11.5	7.0	7.0	0.0	0.0	0.0	0.0	0.0					PM - overcast	
24	8:00	6.5	6.5	6.0	6.0	0.0	0.0	0.0	0.0	0.0					AM - overcast	
25	8:00	6.0	6.0	1.5	1.5	0.0	0.0	0.0	0.0	0.0					PM - overcast	
26	8:00	2.0	2.0	-1.0	-1.0	0.0	0.0	0.0	0.0	0.0					AM - CC 1/2	
27	8:00	2.5	2.5	-1.0	-1.0	0.0	0.0	0.0	0.0	0.0					PM - "	
28	8:00	-2.5	-2.5	-3.0	-3.0	0.0	0.0	0.0	0.0	0.0					AM - CC 1/2	
29	8:00	9.0	9.0	-3.0	-3.0	0.0	0.0	0.0	0.0	0.0					PM - overcast	
30	8:00	4.0	4.0	-1.0	-1.0	0.0	0.0	0.0	0.0	0.0					AM - overcast	
31	8:00	4.0	4.0	-1.0	-1.0	0.0	0.0	0.0	0.0	0.0					PM - overcast	
32	8:00	7.0	7.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0					AM - overcast	
33	8:00	2.0	2.0	-1.5	-1.5	0.0	0.0	0.0	0.0	0.0					PM - overcast	
34	8:00	1.5	1.5	-0.5	-0.5	0.0	0.0	0.0	0.0	0.0					AM - CC 1/2	
35	8:00	1.0	1.0	-1.0	-1.0	0.0	0.0	0.0	0.0	0.0					PM - "	
36	8:00	1.0	1.0	-0.5	-0.5	0.0	0.0	0.0	0.0	0.0					AM - CC 1/2	
37	8:00	2.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0					PM - "	
38	8:00	0.5	0.5	-4.5	-4.5	0.0	0.0	0.0	0.0	0.0					AM - CC 1/2	
39	8:00	2.0	2.0	-4.0	-4.0	0.0	0.0	0.0	0.0	0.0					PM - CC 1/2	
40	8:00	0.0	0.0	-7.0	-7.0	0.0	0.0	0.0	0.0	0.0					AM - CC 1/2	
41	8:00	-1.0	-1.0	-7.5	-7.5	0.0	0.0	0.0	0.0	0.0					PM - overcast	
42	8:00	-3.5	-3.5	-11.0	-11.0	0.0	0.0	0.0	0.0	0.0					AM - CC 1/2	
43	8:00	-8.0	-8.0	-12.0	-12.0	0.0	0.0	0.0	0.0	0.0					PM - overcast	
44	8:00	-12.0	-12.0	-13.5	-13.5	0.0	0.0	0.0	0.0	0.0					AM - overcast, fog	
45	8:00	-6.0	-6.0	-11.0	-11.0	0.0	0.0	0.0	0.0	0.0					PM - CC 1/2	
46	8:00	-7.0	-7.0	-10.0	-10.0	0.0	0.0	0.0	0.0	0.0					AM - overcast	
47	8:00	-4.5	-4.5	-7.0	-7.0	0.0	0.0	0.0	0.0	0.0					PM - overcast, snow	
48	8:00	-2.0	-2.0	-5.0	-5.0	0.0	0.0	0.0	0.0	0.0					AM - "	
49	8:00	-3.0	-3.0	-9.0	-9.0	0.0	0.0	0.0	0.0	0.0					PM - overcast, snow	
50	8:00	-8.5	-8.5	-12.5	-12.5	0.0	0.0	0.0	0.0	0.0					AM - "	
51	8:00	-12.0	-12.0	-15.0	-15.0	0.0	0.0	0.0	0.0	0.0					PM - CC 1/2	
52	8:00	-9.5	-9.5	-12.0	-12.0	0.0	0.0	0.0	0.0	0.0					AM - CC 1/2, snow	
53	8:00	-12.0	-12.0	-16.0	-16.0	0.0	0.0	0.0	0.0	0.0					PM - CC 1/2	
54	8:00	-11.0	-11.0	-15.5	-15.5	0.0	0.0	0.0	0.0	0.0					AM - overcast, snow	
55	8:00	-13.5	-13.5	-17.0	-17.0	0.0	0.0	0.0	0.0	0.0					PM - "	
56	8:00	-16.0	-16.0	-20.5	-20.5	0.0	0.0	0.0	0.0	0.0					AM - CC 1/2	
57	8:00	-18.5	-18.5	-21.0	-21.0	0.0	0.0	0.0	0.0	0.0					PM - CC 1/2	
58	8:00	-17.0	-17.0	-19.5	-19.5	0.0	0.0	0.0	0.0	0.0					AM - overcast	
59	8:00	-17.0	-17.0	-17.0	-17.0	0.0	0.0	0.0	0.0	0.0					PM - " snowing	
60	8:00	-17.0	-17.0	-17.0	-17.0	0.0	0.0	0.0	0.0	0.0					AM - "	
61	8:00	-17.0	-17.0	-17.0	-17.0	0.0	0.0	0.0	0.0	0.0					PM - "	
62	8:00	-17.0	-17.0	-17.0	-17.0	0.0	0.0	0.0	0.0	0.0					AM - "	
63	8:00	-17.0	-17.0	-17.0	-17.0	0.0	0.0	0.0	0.0	0.0					PM - "	
64	8:00	-17.0	-17.0	-17.0	-17.0	0.0	0.0	0.0	0.0	0.0					AM - "	
65	8:00	-17.0	-17.0	-17.0	-17.0	0.0	0.0	0.0	0.0	0.0					PM - "	
66	8:00	-17.0	-17.0	-17.0	-17.0	0.0	0.0	0.0	0.0	0.0					AM - "	
67	8:00	-17.0	-17.0	-17.0	-17.0	0.0	0.0	0.0	0.0	0.0					PM - "	
68	8:00	-17.0	-17.0	-17.0	-17.0	0.0	0.0	0.0	0.0	0.0					AM - "	
69	8:00	-17.0	-17.0	-17.0	-17.0	0.0	0.0	0.0	0.0	0.0					PM - "	
70	8:00	-17.0	-17.0	-17.0	-17.0	0.0	0.0	0.0	0.0	0.0					AM - "	
71	8:00	-17.0	-17.0	-17.0	-17.0	0.0	0.0	0.0	0.0	0.0					PM - "	
72	8:00	-17.0	-17.0	-17.0	-17.0	0.0	0.0	0.0	0.0	0.0					AM - "	
73	8:00	-17.0	-17.0	-17.0	-17.0	0.0	0.0	0.0	0.0	0.0					PM - "	
74	8:00	-17.0	-17.0	-17.0	-17.0	0.0	0.0	0.0	0.0	0.0					AM - "	
75	8:00	-17.0	-17.0	-17.0	-17.0	0.0	0.0	0.0	0.0	0.0					PM - "	
76	8:00	-17.0	-17.0	-17.0	-17.0	0.0	0.0	0.0	0.0	0.0					AM - "	
77	8:00	-17.0	-17.0	-17.0	-17.0	0.0	0.0	0.0	0.0	0.0					PM - "	
78	8:00	-17.0	-17.0	-17.0	-17.0	0.0	0.0	0.0	0.0	0.0					AM - "	
79	8:00	-17.0	-17.0	-17.0	-17.0	0.0	0.0	0.0	0.0	0.0					PM - "	
80	8:00	-17.0	-17.0	-17.0	-17.0	0.0	0.0	0.0	0.0	0.0					AM - "	
81	8:00	-17.0	-17.0	-17.0	-17.0	0.0	0.0	0.0	0.0	0.0					PM - "	
82	8:00	-17.0	-17.0	-17.0	-17.0	0.0	0.0	0.0	0.0	0.0					AM - "	
83	8:00	-17.0	-17.0	-17.0	-17.0	0.0	0.0	0.0	0.0	0.0					PM - "	
84	8:00	-17.0	-17.0	-17.0	-17.0	0.0	0.0	0.0	0.0	0.0					AM - "	
85	8:00	-17.0	-17.0	-17.0	-17.0	0.0	0.0	0.0	0.0	0.0					PM - "	
86	8:00	-17.0	-17.0	-17.0	-17.0	0.0	0.0	0.0	0.0	0.0					AM - "	
87	8:00	-17.0	-17.0	-17.0	-17.0	0.0	0.0	0.0	0.0	0.0					PM - "	
88	8:00	-17.0	-17.0	-17.0	-17.0	0.0	0.0	0.0	0.0	0.0					AM - "	
89	8:00	-17.0	-17.0	-17.0	-17.0	0.0	0.0	0.0	0.0	0.0					PM - "	
90	8:00	-17.0	-17.0	-17.0	-17.0	0.0	0.0	0.0	0.0	0.0					AM - "	
91	8:00	-17.0	-17.0	-17.0	-17.0	0.0	0.0	0.0	0.0	0.0					PM - "	
92	8:00	-17.0	-17.0	-17.0	-17.0	0.0	0.0	0.0	0.0	0.0					AM - "	
93	8:00	-17.0	-17.0	-17.0	-17.0	0.0	0.0	0.0	0.0	0.0					PM - "	
94	8:00	-17.0	-17.0	-17.0	-17.0	0.0	0.0	0.0	0.0	0.0					AM - "	
95	8:00	-17.0	-17.0	-17.0	-17.0	0.0	0.0	0.0	0.0	0.0					PM - "	
96	8:00	-17.0	-17.0	-17.0	-17.0	0.0	0.0	0.0	0.0	0.0					AM - "	
97	8:00	-17.0	-17.0	-17.0	-17.0	0.										

TABLE B4

1. Instrument
2. Location
3. Date
4. Time

METRIC
CLIMATOLOGICAL STATION REPORT

STATION

PROVINCE

Time of observation 8:50 a.m. 12:30 p.m.

T
P

Observer PETER WINTO & SLDON KIRIANMONTH December19 54

DAY OF MONTH	TIME OF OBSERVATION	TEMPERATURE (°C)					PRECIPITATION					TIME OF PRECIPITATION (Colder Day)		Weather (Colder Day)		REMARKS			
		Maximum		Minimum		AFTER RESEY	Rain		Snow		Total Per Day	Began	Ended	Depth of Snow on Ground (mm)	Thunderstorm (mm)				
		Observed	Per Day	Observed	Per Day		mm	mm	mm	mm					mm		mm	mm	mm
1	a.m.	-16.0	-19.5	-20.0	-19.5										9		AM - overcast PM - CC 3/10		
2	a.m.	-17.5	-20.5	-21.5	-21.5										9		AM - CC 7/10 PM - CC 1/10, blowing snow		
3	a.m.	-17.5	-20.5	-21.5	-21.5										9		AM - overcast, light snow PM - CC 4/10		
4	a.m.	-18.0	-21.0	-22.0	-22.0										9		AM - overcast, snowing PM - CC 8/10		
5	a.m.	-18.0	-21.0	-22.0	-22.0										9		AM - clear PM - CC 8/10		
6	a.m.	-18.0	-21.0	-22.0	-22.0										9		AM - CC 7/10 PM - CC 1/10		
7	a.m.	-18.0	-21.0	-22.0	-22.0										9		AM - overcast, snow PM - CC 7/10		
8	a.m.	-18.0	-21.0	-22.0	-22.0										14		AM - overcast, snow PM - " "		
9	a.m.	-18.0	-21.0	-22.0	-22.0										17		AM - fog PM - CC 3/10		
10	a.m.	-18.0	-21.0	-22.0	-22.0										17		AM - overcast PM - CC 9/10		
11	a.m.	-18.0	-21.0	-22.0	-22.0										17		AM - overcast, snow PM - " "		
12	a.m.	-18.0	-21.0	-22.0	-22.0										17		AM - " snow PM - " "		
13	a.m.	-18.0	-21.0	-22.0	-22.0										26		AM - " " PM - " "		
14	a.m.	-18.0	-21.0	-22.0	-22.0										25		AM - " " PM - " "		
15	a.m.	-18.0	-21.0	-22.0	-22.0										20		AM - CC 3/10 PM - CC 3/10		
16	a.m.	-18.0	-21.0	-22.0	-22.0										20		AM - clear PM - clear		
17	a.m.	-18.0	-21.0	-22.0	-22.0										25		AM - CC 4/10 PM - CC 4/10		
18	a.m.	-18.0	-21.0	-22.0	-22.0										24		AM - clear PM - CC 2/10		
19	a.m.	-18.0	-21.0	-22.0	-22.0										24		AM - CC 4/10 PM - overcast, light snow		
20	a.m.	-18.0	-21.0	-22.0	-22.0										22		AM - " PM - overcast		
21	a.m.	-18.0	-21.0	-22.0	-22.0										29		AM - " PM - "		
22	a.m.	-18.0	-21.0	-22.0	-22.0										25		AM - CC 8/10 PM - "		
23	a.m.	-18.0	-21.0	-22.0	-22.0										25		AM - " PM - overcast		
24	a.m.	-18.0	-21.0	-22.0	-22.0										25		AM - " PM - CC 2/10		
25	a.m.	-18.0	-21.0	-22.0	-22.0										25		AM - clear PM - "		
26	a.m.	-18.0	-21.0	-22.0	-22.0										25		AM - CC 3/10 PM - clear		
27	a.m.	-18.0	-21.0	-22.0	-22.0										25		AM - CC 3/10 PM - clear		
28	a.m.	-18.0	-21.0	-22.0	-22.0										25		AM - CC 2/10 PM - clear		
29	a.m.	-18.0	-21.0	-22.0	-22.0										25		AM - overcast PM - "		
30	a.m.	-18.0	-21.0	-22.0	-22.0										25		AM - " snowing PM - CC 9/10, snowing		
31	a.m.	-18.0	-21.0	-22.0	-22.0										26		AM - CC 8/10 PM - CC 4/10, light snow		
1	a.m.	-18.0	-21.0	-22.0	-22.0														
Total no. of days with																			
SUM		-356		-602		0.3		31.5		2.1		Temperature extremes		Mean Max. -12.8		Mean Min. -21.0			
MEAN		-18.0		-21.0								Minimum -37.5		Date 17		Mean -16.5			

DATE	TIME	TEMPERATURE		PRECIPITATION	WIND	WEATHER	REMARKS
		Maximum	Minimum				
1954	12:30	-18.0	-21.0	0.3	3/3	1/1	

TEMPERATURE EXTREMES

Maximum: 1.5 Date: 2

Minimum: -27.5 Date: 17

TEMPERATURE

Mean Max: -12.8

Mean Min: -21.0

Mean: -16.5

TABLE B5

Environment Canada
Environnement Canada

METRIC
CLIMATOLOGICAL STATION REPORT

STATION _____

Time of observation 800 a.m. 630 p.m.

T ☒
P ☒

PROVINCE _____

Observer *Eden, John & Matt Sault*MONTH *December* 19 *94*

DAY OF MONTH	TIME OF OBSERVATION	TEMPERATURE (°C)					PRECIPITATION					TIMES OF PRECIPITATION (Calendar Day)		Depth of Snow on Ground (cm)	Weather (Calendar Day)	REMARKS
		Maximum		Minimum		Rain	Snow		Total For Day	Begin	End					
		Observed	For Day	Observed	For Day		After Reset	Measured				For Day	Measured			
1	a.m.			-30.0												AM - overcast, snowing
1	p.m.	-18.0	-15.0	-23.5	-20.0	-18.5			0.1	0.1	0.1			25		PM - CC 8/10
2	a.m.	-5.5		-21.0		-19.5										AM - overcast
2	p.m.	-15.5	-12.5	-28.0	-21.0	-14.0			0.1	0.1	0.1			26		PM - "
3	a.m.	-14.0		-21.0		-15.5										AM - "
3	p.m.	-5.0	-15.0	-23.0	-22.0	-21.0								26		PM - CC 5/10
4	a.m.	-9.0		-25.0		-19.0										AM - overcast
4	p.m.	-7.0	-14.0	-24.0	-24.0	-21.0								25		PM - clear
5	a.m.	-24.0		-38.0		-36.5										AM - CC 5/10
5	p.m.	-20.5	-12.0	-17.0	-24.0	-20.5										PM - CC 5/10
6	a.m.	-13.0		-20.5		-19.0										AM - CC 7/10
6	p.m.	-4.0	+1.0	-22.0	-20.5	-4.0	1.7							26		PM - CC 8/10
7	a.m.	-2.0		-6.0		1.0										AM - CC 9/10
7	p.m.	1.5	1.5	-7.5	-6.0	0.0								25		PM - "
8	a.m.	-7.0		-13.0		-12.0			1.5	1.5	1.5					AM - Fog
8	p.m.	-5.0	-4.0	-12.0	-13.0	-5.0								25		PM - overcast
9	a.m.	-7.0		-13.0		-11.0										AM - clear
9	p.m.	-6.0	-4.5	-17.0	-13.0	-6.0								27		PM - CC 5/10
10	a.m.	-4.5		-23.0		-7.0										AM - CC 7/10
10	p.m.	-7.0	-7.0	-24.0	-24.0	-7.0								27		PM - overcast
11	a.m.	-24.0		-32.5		-22.5										AM - clear
11	p.m.	-21.5	-22.0	-34.5	-34.5	-26.5								28		PM - CC 7/10
12	a.m.	-27.0		-40.0		-23.0										AM - overcast, snow
12	p.m.	-25.0	-25.0	-28.5	-40.0	-28.5			2.9	0.5	3.4			25		PM - clear
13	a.m.	-25.5		-40.0		-23.0										AM - clear
13	p.m.	-25.0	-18.5	-40.0	-40.0	-25.0								20		PM - CC 9/10
14	a.m.	-18.5		-27.0		-18.5										AM - CC 7/10
14	p.m.	-11.5	-10.0	-18.5	-22.0	-11.0								29		PM - overcast
15	a.m.	-3.0		-25.0		-25.0										AM - CC 3/10
15	p.m.	-21.0	-21.0	-25.0	-28.0	-28.0								25		PM - CC 9/10
16	a.m.	-28.0		-37.0		-37.0										AM - CC 1/10
16	p.m.	-22.0	-22.0	-38.0	-38.0	-36.0								20		PM - clear
17	a.m.	-22.0		-37.0		-37.0										AM - CC 3/10
17	p.m.	-24.0	-24.0	-37.0	-39.0	-27.0			0.2	0.2	0.2			20		PM - CC 5/10
18	a.m.	-21.0		-37.0		-22.0			0.2	0.2	0.2					AM - overcast
18	p.m.	-19.0	-15.0	-22.0	-22.0	-19.0								27		PM - overcast, snow
19	a.m.	-19.0		-21.0		-20.0			0.3	0.3	0.3					AM - CC 1/10
19	p.m.	-20.0	-20.0	-34.5	-34.5	-24.5								26		PM - clear
20	a.m.	-23.0		-38.0		-24.0										AM - overcast, snow
20	p.m.	-21.5	-21.5	-40.0	-34.0	-29.0			2.2	2.2	2.2			29		PM - "
21	a.m.	-22.0		-38.0		-34.0										AM - clear
21	p.m.	-31.5	-27.5	-35.0	-35.0	-21.5	0.3	0.5	0.5					37		PM - CC 3/10
22	a.m.	-27.5		-33.0		-29.5										AM - overcast
22	p.m.	-24.0	-24.0	-35.0	-35.0	-35.0								30		PM - CC 7/10
23	a.m.	-35.0		-38.5		-38.0										AM - clear
23	p.m.	-21.5	-41.0	-18.0	-18.0	-23.5								30		PM - "
24	a.m.	-14.0		-35.0		-32.5										AM - "
24	p.m.	-11.5	-11.5	-40.0	-35.0	-32.5								30		PM - "
25	a.m.	-22.5		-37.0		-34.0										AM - "
25	p.m.	-30.0	-32.0	-42.0	-40.0	-34.0								30		PM - "
26	a.m.	-14.0		-35.0		-31.0										AM - "
26	p.m.	-32.5	-15.0	-49.0	-44.0	-30.5			1.8	2.2	2.2			30		PM - overcast, snow
27	a.m.	-30.5		-43.0		-41.0			0.4	0.4	0.4					AM - clear
27	p.m.	-31.0	-33.0	-43.5	-43.5	-37.0								-		PM - "
28	a.m.	-36.0		-42.0		-41.0										AM - "
28	p.m.	-37.0	-7.0	-41.5	-42.0	-32.0								-		PM - "
29	a.m.	-34.0		-42.0		-40.5										AM - "
29	p.m.	-34.0	-43.0	-40.5	-42.0	-34.5								-		PM - "
30	a.m.	-44.0		-38.0		-33.5										AM - "
30	p.m.	-28.5	-17.0	-36.0	-36.0	-31.0								-		PM - partly cloudy
31	a.m.	-30.5		-36.5		-32.0										AM - clear
31	p.m.	-28.5	-28.5	-36.5	-36.5	-31.0								-		PM - clear
1	a.m.	-29.5		-36.5		-32.0										

SUM -19.0 1021.0

MEANS -20.4 -33.7

1.7 100 11.7

TEMPERATURE EXTREMES
Maximum: 2.0 Date: 7
Minimum: -55.0 Date: 24

TEMPERATURE
Mean Max: 20.9
Mean Min: -33.2

TABLE B6

METRIC
CLIMATOLOGICAL STATION REPORT

T	
P	

STATION 7.5PROVINCE Sorsogon

Observer

MONTH JAN 19 77

DAY OF MONTH	TIME OF OBSERVATION	TEMPERATURE (°C)					PRECIPITATION					TIME OF PRECIPITATION (Calendar Day)		Depth of Snow on Ground (Thousandths of an Inch)	Weather (Calendar Day)	REMARKS		
		Maximum		Minimum		Rain	Snow		Time Per Day	Begin	End							
		Observed	Per Day	Observed	Per Day		Observed	Per Day										
												AFTER RESET						
1	a.m.	Observed	Per Day	Observed	Per Day	AFTER RESET	Observed	Per Day	Observed	Per Day	Time Per Day	Begin	End	15	16	17	18	19
1	a.m.	-2.0	-4.0	-3.0	-4.0	-3.0												
2	a.m.	-4.0	-6.0	-3.5	-4.5	-3.5												
3	a.m.	-1.0	-3.0	-2.0	-3.0	-2.0												
4	a.m.	-2.5	-4.5	-3.5	-4.5	-3.5												
5	a.m.	-1.0	-3.0	-2.0	-3.0	-2.0												
6	a.m.	-1.0	-3.0	-2.0	-3.0	-2.0												
7	a.m.	-2.0	-4.0	-3.0	-4.0	-3.0												
8	a.m.	-3.0	-5.0	-4.0	-5.0	-4.0												
9	a.m.	-2.5	-4.5	-3.5	-4.5	-3.5												
10	a.m.	-2.0	-4.0	-3.0	-4.0	-3.0												
11	a.m.	-1.5	-3.5	-2.5	-3.5	-2.5												
12	a.m.	-1.0	-3.0	-2.0	-3.0	-2.0												
13	a.m.	-1.5	-3.5	-2.5	-3.5	-2.5												
14	a.m.	-2.0	-4.0	-3.0	-4.0	-3.0												
15	a.m.	-2.5	-4.5	-3.5	-4.5	-3.5												
16	a.m.	-3.0	-5.0	-4.0	-5.0	-4.0												
17	a.m.	-3.5	-5.5	-4.5	-5.5	-4.5												
18	a.m.	-4.0	-6.0	-5.0	-6.0	-5.0												
19	a.m.	-4.5	-6.5	-5.5	-6.5	-5.5												
20	a.m.	-5.0	-7.0	-6.0	-7.0	-6.0												
21	a.m.	-5.5	-7.5	-6.5	-7.5	-6.5												
22	a.m.	-6.0	-8.0	-7.0	-8.0	-7.0												
23	a.m.	-6.5	-8.5	-7.5	-8.5	-7.5												
24	a.m.	-7.0	-9.0	-8.0	-9.0	-8.0												
25	a.m.	-7.5	-9.5	-8.5	-9.5	-8.5												
26	a.m.	-8.0	-10.0	-9.0	-10.0	-9.0												
27	a.m.	-8.5	-10.5	-9.5	-10.5	-9.5												
28	a.m.	-9.0	-11.0	-10.0	-11.0	-10.0												
29	a.m.	-9.5	-11.5	-10.5	-11.5	-10.5												
30	a.m.	-10.0	-12.0	-11.0	-12.0	-11.0												
31	a.m.	-10.5	-12.5	-11.5	-12.5	-11.5												
32	a.m.	-11.0	-13.0	-12.0	-13.0	-12.0												
33	a.m.	-11.5	-13.5	-12.5	-13.5	-12.5												
34	a.m.	-12.0	-14.0	-13.0	-14.0	-13.0												
35	a.m.	-12.5	-14.5	-13.5	-14.5	-13.5												
36	a.m.	-13.0	-15.0	-14.0	-15.0	-14.0												
37	a.m.	-13.5	-15.5	-14.5	-15.5	-14.5												
38	a.m.	-14.0	-16.0	-15.0	-16.0	-15.0												
39	a.m.	-14.5	-16.5	-15.5	-16.5	-15.5												
40	a.m.	-15.0	-17.0	-16.0	-17.0	-16.0												
41	a.m.	-15.5	-17.5	-16.5	-17.5	-16.5												
42	a.m.	-16.0	-18.0	-17.0	-18.0	-17.0												
43	a.m.	-16.5	-18.5	-17.5	-18.5	-17.5												
44	a.m.	-17.0	-19.0	-18.0	-19.0	-18.0												
45	a.m.	-17.5	-19.5	-18.5	-19.5	-18.5												
46	a.m.	-18.0	-20.0	-19.0	-20.0	-19.0												
47	a.m.	-18.5	-20.5	-19.5	-20.5	-19.5												
48	a.m.	-19.0	-21.0	-20.0	-21.0	-20.0												
49	a.m.	-19.5	-21.5	-20.5	-21.5	-20.5												
50	a.m.	-20.0	-22.0	-21.0	-22.0	-21.0												
51	a.m.	-20.5	-22.5	-21.5	-22.5	-21.5												
52	a.m.	-21.0	-23.0	-22.0	-23.0	-22.0												
53	a.m.	-21.5	-23.5	-22.5	-23.5	-22.5												
54	a.m.	-22.0	-24.0	-23.0	-24.0	-23.0												
55	a.m.	-22.5	-24.5	-23.5	-24.5	-23.5												
56	a.m.	-23.0	-25.0	-24.0	-25.0	-24.0												
57	a.m.	-23.5	-25.5	-24.5	-25.5	-24.5												
58	a.m.	-24.0	-26.0	-25.0	-26.0	-25.0												
59	a.m.	-24.5	-26.5	-25.5	-26.5	-25.5												
60	a.m.	-25.0	-27.0	-26.0	-27.0	-26.0												
61	a.m.	-25.5	-27.5	-26.5	-27.5	-26.5												
62	a.m.	-26.0	-28.0	-27.0	-28.0	-27.0												
63	a.m.	-26.5	-28.5	-27.5	-28.5	-27.5												
64	a.m.	-27.0	-29.0	-28.0	-29.0	-28.0												
65	a.m.	-27.5	-29.5	-28.5	-29.5	-28.5												
66	a.m.	-28.0	-30.0	-29.0	-30.0	-29.0												
67	a.m.	-28.5	-30.5	-29.5	-30.5	-29.5												
68	a.m.	-29.0	-31.0	-30.0	-31.0	-30.0												
69	a.m.	-29.5	-31.5	-30.5	-31.5	-30.5												
70	a.m.	-30.0	-32.0	-31.0	-32.0	-31.0												
71	a.m.	-30.5	-32.5	-31.5	-32.5	-31.5												
72	a.m.	-31.0	-33.0	-32.0	-33.0	-32.0												
73	a.m.	-31.5	-33.5	-32.5	-33.5	-32.5												
74	a.m.	-32.0	-34.0	-33.0	-34.0	-33.0												
75	a.m.	-32.5	-34.5	-33.5	-34.5	-33.5												
76	a.m.	-33.0	-35.0	-34.0	-35.0	-34.0												
77	a.m.	-33.5	-35.5	-34.5	-35.5	-34.5												
78	a.m.	-34.0	-36.0	-35.0	-36.0	-35.0												
79	a.m.	-34.5	-36.5	-35.5	-36.5	-35.5												
80	a.m.	-35.0	-37.0	-36.0	-37.0	-36.0												
81	a.m.	-35.5	-37.5	-36.5	-37.5	-36.5												
82	a.m.	-36.0	-38.0	-37.0	-38.0	-37.0												
83	a.m.	-36.5	-38.5	-37.5	-38.5	-37.5												
84	a.m.	-37.0	-39.0	-38.0	-39.0	-38.0												
85	a.m.	-37.5	-39.5	-38.5	-39.5	-38.5												
86	a.m.	-38.0	-40.0	-39.0	-40.0	-39.0												
87	a.m.	-38.5	-40.5	-39.5	-40.5	-39.5												
88	a.m.	-39.0	-41.0	-40.0	-41.0	-40.0												
89	a.m.	-39.5	-41.5	-40.5	-41.5	-40.5												
90	a.m.	-40.0	-42.0	-41.0	-42.0	-41.0												
91	a.m.	-40.5	-42.5	-41.5	-42.5	-41.5												
92	a.m.	-41.0	-43.0	-42.0	-43.0	-42.0												
93	a.m.	-41.5	-43.5	-42.5	-43.5	-42.5												
94	a.m.	-42.0	-44.0	-43.0	-44.0	-43.0												
95	a.m.	-42.5	-44.5	-43.5	-44.5	-43.5												
96	a.m.	-43.0	-45.0	-44.0	-45.0	-44.0												
97	a.m.	-43.5	-45.5	-44.5	-45.5	-44.5												
98	a.m.	-44.0	-46.0	-45.0	-46.0	-45.0												
99	a.m.	-44.5	-46.5	-45.5	-46.5	-45.5												
100	a.m.	-45.0	-47.0	-46.0	-47.0	-46.0												
101	a.m.	-45.5	-47.5	-46.5	-47.5	-46.5												
102	a.m.	-46.0	-48.0	-47.0	-48.0	-47.0												
103	a.m.	-46.5	-48.5	-47.5	-48.5	-47.5												
104	a.m.	-47.0	-49.0	-48.0	-49.0	-48.0												
105	a.m.	-47.5	-49.5	-48.5	-49.5	-48.5												
106	a.m.	-48.0	-50.0	-49.0	-50.0	-49.0												
107	a.m.	-48.5	-50.5	-49.5	-50.5	-49.5												
108	a.m.	-49.0	-51.0	-50.0	-51.0	-50.0												
109	a.m.	-49.5	-51.5	-50.5	-51.5	-50.5												
110	a.m.	-50.0	-52.0	-51.0	-52.0	-51.0												
111	a.m.	-50																

TABLE B7

1. Temperature
2. Precipitation
3. Wind
4. Humidity
5. Clouds
6. Barometer
7. Direction
8. State of sky
9. Remarks

METRIC
CLIMATOLOGICAL STATION REPORT

STATION K. LakeTime of observation 8:00 a.m. 6:30 p.m.PROVINCE SaskObserver Kat S. G. Wilson K. LakeMONTH February 19 85

DAY OF MONTH	TIME OF OBSERVATION	TEMPERATURE °C				PRECIPITATION				TIME OF PRECIPITATION (Calendar Day)		Weather (Calendar Day)		REMARKS
		Maximum		Minimum		Rain		Snow		Begin	End	Amount (mm)	Direction	
		Observed	For Day	Observed	For Day	Observed	For Day	Observed	For Day					
1	a.m.			-4.0	-5.0	-40.0								Am - CC 1/10
1	p.m.	-33.0	-33.0	-41.5	-41.5	-41.0								Am - CC 1/10
2	a.m.	-36.0	-36.0	-45.0	-45.0	-44.5								Am - CC 1/10
2	p.m.	-34.0	-34.0	-45.0	-45.0	-36.0								Am - CC 1/10
3	a.m.	-36.0	-36.0	-39.0	-39.0	-32.0								Am - CC 1/10
3	p.m.	-27.0	-27.0	-37.0	-37.0	-24.5								Am - CC 1/10
4	a.m.	-24.0	-24.0	-28.0	-28.0	-24.0								Am - CC 1/10, light snow
4	p.m.	-20.0	-20.0	-24.5	-24.5	-24.5								Am - CC 1/10
5	a.m.	-24.5	-24.5	-37.5	-37.5	-31.0								Am - CC 1/10
5	p.m.	-19.0	-19.0	-18.0	-18.0	-10.0								Am - CC 1/10
6	a.m.	-10.0	-10.0	-40.0	-40.0	-40.5								Am - CC 1/10, ice fog
6	p.m.	-29.0	-29.0	-41.5	-41.5	-31.5								Am - CC 1/10
7	a.m.	-37.5	-37.5	-30.0	-30.0	-37.5								Am - CC 1/10
7	p.m.	-27.0	-27.0	-37.5	-37.5	-38.0								Am - CC 1/10
8	a.m.	-30.0	-30.0	-35.0	-35.0	-30.0								Am - CC 1/10, light snow
8	p.m.	-23.0	-23.0	-30.0	-30.0	-21.5								Am - CC 1/10
9	a.m.	-21.5	-21.5	-25.0	-25.0	-23.5								Am - overcast, ice fog, snow
9	p.m.	-22.0	-22.0	-24.0	-24.0	-23.5								Am - CC 1/10
10	a.m.	-23.5	-23.5	-19.0	-19.0	-15.5								Am - CC 1/10
10	p.m.	-24.0	-24.0	-19.0	-19.0	-24.0								Am - clear
11	a.m.	-24.0	-24.0	-16.0	-16.0	-15.0								Am - "
11	p.m.	-22.0	-22.0	-16.0	-16.0	-26.0								Am - "
12	a.m.	-22.0	-22.0	-15.0	-15.0	-22.0								Am - overcast
12	p.m.	-19.5	-19.5	-23.5	-23.5	-27.5								Am - CC 1/10
13	a.m.	-22.5	-22.5	-13.0	-13.0	-28.0								Am - clear
13	p.m.	-24.5	-24.5	-15.5	-15.5	-28.0								Am - CC 1/10
14	a.m.	-24.0	-24.0	-14.5	-14.5	-41.5								Am - clear
14	p.m.	-22.5	-22.5	-14.5	-14.5	-22.5								Am - CC 1/10
15	a.m.	-4.5	-4.5	-21.0	-21.0	-20.0								Am - overcast
15	p.m.	-15.5	-15.5	-20.0	-20.0	-15.5								Am - "
16	a.m.	-15.0	-15.0	-22.0	-22.0	-22.5								Am - " snow
16	p.m.	-22.5	-22.5	-24.0	-24.0	-24.0								Am - CC 1/10
17	a.m.	-26.0	-26.0	-23.0	-23.0	-20.5								Am - CC 1/10
17	p.m.	-27.5	-27.5	-35.0	-35.0	-28.0								Am - CC 1/10
18	a.m.	-28.0	-28.0	-24.0	-24.0	-28.0								Am - clear
18	p.m.	-21.0	-21.0	-40.5	-40.5	-21.0								Am - CC 1/10
19	a.m.	-16.0	-16.0	-22.5	-22.5	-24.0								Am - overcast
19	p.m.	-5.0	-5.0	-27.0	-27.0	-5.0								Am - "
20	a.m.	-7.0	-7.0	-31.0	-31.0	-25.0								Am - clear
20	p.m.	-27.0	-27.0	-24.0	-24.0	-26.0								Am - overcast, blowing snow
21	a.m.	-27.0	-27.0	-36.5	-36.5	-26.0								Am - fog
21	p.m.	-17.0	-17.0	-36.5	-36.5	-21.0								Am - overcast
22	a.m.	-23.0	-23.0	-23.0	-23.0	-24.5								Am - "
22	p.m.	-21.0	-21.0	-24.5	-24.5	-19.0								Am - CC 1/10
23	a.m.	-25.0	-25.0	-18.0	-18.0	-24.0								Am - overcast, snow
23	p.m.	-21.0	-21.0	-30.0	-30.0	-21.0								Am - "
24	a.m.	-21.0	-21.0	-40.5	-40.5	-30.0								Am - CC 1/10
24	p.m.	-16.5	-16.5	-31.0	-31.0	-24.0								Am - CC 1/10
25	a.m.	-20.0	-20.0	-31.0	-31.0	-22.0								Am - CC 1/10
25	p.m.	-14.0	-14.0	-36.0	-36.0	-22.5								Am - clear
26	a.m.	-17.5	-17.5	-30.0	-30.0	-18.5								Am - overcast, ice fog, snow
26	p.m.	-8.5	-8.5	-19.5	-19.5	-9.5								Am - "
27	a.m.	-4.0	-4.0	-11.0	-11.0	-9.0								Am - clear
27	p.m.	-2.0	-2.0	-10.0	-10.0	-3.0								Am - overcast, snow
28	a.m.	-17.0	-17.0	-7.0	-7.0	-7.0								Am - overcast
28	p.m.	-5.5	-5.5	-7.0	-7.0	-0.0								Am - clear
29	a.m.													
29	p.m.													
30	a.m.													
30	p.m.													
31	a.m.													
31	p.m.													
1	a.m.	-40.0	-40.0											
1	p.m.													
2	a.m.													
2	p.m.													
3	a.m.													
3	p.m.													
4	a.m.													
4	p.m.													
5	a.m.													
5	p.m.													
6	a.m.													
6	p.m.													
7	a.m.													
7	p.m.													
8	a.m.													
8	p.m.													
9	a.m.													
9	p.m.													
10	a.m.													
10	p.m.													
11	a.m.													
11	p.m.													
12	a.m.													
12	p.m.													
13	a.m.													
13	p.m.													
14	a.m.													
14	p.m.													
15	a.m.													
15	p.m.													
16	a.m.													
16	p.m.													
17	a.m.													
17	p.m.													
18	a.m.													
18	p.m.													
19	a.m.													
19	p.m.													
20	a.m.													
20	p.m.													
21	a.m.													
21	p.m.													
22	a.m.													
22	p.m.													
23	a.m.													
23	p.m.													
24	a.m.													
24	p.m.													
25	a.m.													
25	p.m.													
26	a.m.													
26	p.m.													
27	a.m.													
27	p.m.													
28	a.m.													
28	p.m.													
29	a.m.													
29	p.m.													
30	a.m.													
30	p.m.													
31	a.m.													
31	p.m.													
1	a.m.													
1	p.m.													
2	a.m.													
2	p.m.													
3	a.m.													
3	p.m.													
4	a.m.													
4	p.m.													
5	a.m.													
5	p.m.													
6	a.m.													
6	p.m.													
7	a.m.													
7	p.m.													
8	a.m.													
8	p.m.													
9	a.m.													

TABLE B8

14 Canadian Climate
Environment Canada
Environment International

METRIC
CLIMATOLOGICAL STATION REPORT

STATION Key LakeTime of observation 8:00 a.m. 6:50 p.m.

T ☒
P ☒

PROVINCE SaskObserver Elden Koehn - Kait VartyMONTH Mar19 75

DAY OF MONTH	TIME OF OBSERVATION	TEMPERATURE °C				PRECIPITATION				TIME OF PRECIPITATION (Calendar Day)		Depth of Snow on Ground (mm)	Weather (Calendar Day)	REMARKS
		Maximum		Minimum		Rain		Snow		Start	End			
		Observed	For Day	Observed	For Day	Observed	For Day	Observed	For Day	Observed	For Day			
1	8:00	-11.0	-11.0	-17.0	-11.0							52	AM - overcast PM - clear	
2	8:00	-12.5	-12.5	-31.0	-17.5							51	AM - clear PM - CC 7/10	
3	8:00	-13.0	-13.0	-30.5	-18.0							51	AM - CC 7/10 PM - overcast, light snow	
4	8:00	-9.5	-9.5	-16.5	-10.0							52	AM - overcast, light snow PM - CC 7/10	
5	8:00	-10.5	-10.5	-25.0	-10.5							51	AM - CC 7/10 PM - CC 7/10	
6	8:00	-5.0	-5.0	-25.0	-5.0							51	AM - CC 7/10 PM - CC 7/10	
7	8:00	-13.0	-13.0	-14.0	-13.0							53	AM - overcast, light snow PM - CC 7/10	
8	8:00	-6.0	-6.0	-14.0	-6.0							52	AM - CC 7/10 PM - CC 7/10	
9	8:00	-1.0	-1.0	-14.0	-1.0							50	AM - CC 7/10 PM - CC 7/10	
10	8:00	0.0	0.0	-11.5	0.0							49	AM - CC 7/10 PM - CC 7/10	
11	8:00	-3.0	-3.0	-11.5	-3.0							49	AM - CC 7/10 PM - overcast	
12	8:00	-13.0	-13.0	-5.5	-13.0							49	AM - CC 7/10 PM - CC 7/10	
13	8:00	-13.0	-13.0	-9.5	-13.0									
14	8:00													
15	8:00													
16	8:00													
17	8:00													
18	8:00													
19	8:00													
20	8:00													
21	8:00													
22	8:00													
23	8:00													
24	8:00													
25	8:00													
26	8:00													
27	8:00													
28	8:00													
29	8:00													
30	8:00													
31	8:00													
Total no. of days with														
SLASH		-60.5		-23		TEMPERATURE EXTREMES				TEMPERATURE				
MEANS		-5.0		-18.6		Maximum.....Date.....				Minimum.....Date.....				

TABLE B9

[illegible]

TABLE B10

INLAND & FLEETED LLC

FILE #1111111111

KEY LANE PROJECT
 MONITORING OF LAMPED URANIUM TAILINGS PHASE 1
 MONTHLY DATA SUMMARY SEPTEMBER 2018

	channel #1			channel #15			#11	#12	#13	#14	#15
DAY	AIR TEMPERATURE (deg C)			AIR TEMPERATURE (deg C)			RYAN (W/m2/day)	FLEETED (mm)	FLOW (liters)	INDY (m)	TIME (hrs)
	av	max	min	av	max	min	total	total	total	av	hrs
1	11.7	17.7	5.9	11.7	17.7	5.9	3484	0.3	0.3	0.3	0.3
2	11.7	17.7	5.9	11.7	17.7	5.9	3484	0.3	0.3	0.3	0.3
3	11.7	17.7	5.9	11.7	17.7	5.9	3484	0.3	0.3	0.3	0.3
4	11.7	17.7	5.9	11.7	17.7	5.9	3484	0.3	0.3	0.3	0.3
5	11.7	17.7	5.9	11.7	17.7	5.9	3484	0.3	0.3	0.3	0.3
6	11.7	17.7	5.9	11.7	17.7	5.9	3484	0.3	0.3	0.3	0.3
7	11.7	17.7	5.9	11.7	17.7	5.9	3484	0.3	0.3	0.3	0.3
8	11.7	17.7	5.9	11.7	17.7	5.9	3484	0.3	0.3	0.3	0.3
9	11.7	17.7	5.9	11.7	17.7	5.9	3484	0.3	0.3	0.3	0.3
10	11.7	17.7	5.9	11.7	17.7	5.9	3484	0.3	0.3	0.3	0.3
11	11.7	17.7	5.9	11.7	17.7	5.9	3484	0.3	0.3	0.3	0.3
12	11.7	17.7	5.9	11.7	17.7	5.9	3484	0.3	0.3	0.3	0.3
13	11.7	17.7	5.9	11.7	17.7	5.9	3484	0.3	0.3	0.3	0.3
14	11.7	17.7	5.9	11.7	17.7	5.9	3484	0.3	0.3	0.3	0.3
15	11.7	17.7	5.9	11.7	17.7	5.9	3484	0.3	0.3	0.3	0.3
16	11.7	17.7	5.9	11.7	17.7	5.9	3484	0.3	0.3	0.3	0.3
17	11.7	17.7	5.9	11.7	17.7	5.9	3484	0.3	0.3	0.3	0.3
18	11.7	17.7	5.9	11.7	17.7	5.9	3484	0.3	0.3	0.3	0.3
19	11.7	17.7	5.9	11.7	17.7	5.9	3484	0.3	0.3	0.3	0.3
20	11.7	17.7	5.9	11.7	17.7	5.9	3484	0.3	0.3	0.3	0.3
21	11.7	17.7	5.9	11.7	17.7	5.9	3484	0.3	0.3	0.3	0.3
22	11.7	17.7	5.9	11.7	17.7	5.9	3484	0.3	0.3	0.3	0.3
23	11.7	17.7	5.9	11.7	17.7	5.9	3484	0.3	0.3	0.3	0.3
24	11.7	17.7	5.9	11.7	17.7	5.9	3484	0.3	0.3	0.3	0.3
25	11.7	17.7	5.9	11.7	17.7	5.9	3484	0.3	0.3	0.3	0.3
26	11.7	17.7	5.9	11.7	17.7	5.9	3484	0.3	0.3	0.3	0.3
27	11.7	17.7	5.9	11.7	17.7	5.9	3484	0.3	0.3	0.3	0.3
28	11.7	17.7	5.9	11.7	17.7	5.9	3484	0.3	0.3	0.3	0.3
29	11.7	17.7	5.9	11.7	17.7	5.9	3484	0.3	0.3	0.3	0.3
30	11.7	17.7	5.9	11.7	17.7	5.9	3484	0.3	0.3	0.3	0.3

#.....NO DATA COLLECTED FOR THIS DATE

#.....SENSOR MALFUNCTIONING

NOTES....

RESULTS ARE DAILY AVERAGE OR TOTAL OF AVAILABLE DATA WITH TYPICAL
 SAMPLING FREQUENCY OF 2 SCANS DAILY BASED ON 8AM TO 8PM DAY.
 TEMPERATURES BELOW APPROXIMATELY -27 C ARE REPORTED AS -27 C.

10-17-1999

TABLE B11

PROJECT: 2. PLEASANT LAGOON

FILE #111PLAIN10

121 LINE PROJECT
 MONITORING OF LAYERED URANIUM TAILINGS PHASE 2
 MONTHLY DATA SUMMARY DECEMBER 1985

DAY	channel #2			channel #12			#11	#12	#13	#14	#15
	AIR TEMPERATURE			AIR TEMPERATURE			PIRAN	PREDIP	ELEV	WINDY	WIND
	(deg C)			(deg C)			W/m2/day	(mm)	(inches)	(%)	RUN
	av	max	min	av	max	min	total	total	total	av	(km/h)
1	#	#	#	#	#	#	#	#	#	#	#
2	#	#	#	#	#	#	#	#	#	#	#
3	#	#	#	#	#	#	#	#	#	#	#
4	#	#	#	#	#	#	#	#	#	#	#
5	4.4	12.7	-1.7	#	#	#	2110	0.0	1270	#	#
6	2.4	3.1	-1.7	#	#	#	2131	0.0	1270	#	#
7	12.1	15.0	1.1	#	#	#	2275	0.0	1191	#	#
8	13.3	20.8	2.2	#	#	#	1951	0.0	1150	#	#
9	14.2	22.7	5.5	#	#	#	2590	0.0	1130	#	#
10	17.8	20.4	8.6	#	#	#	1391	0.0	1110	#	#
11	10.9	12.5	9.9	#	#	#	522	0.0	1090	#	#
12	9.9	11.8	5.6	#	#	#	501	0.0	1050	#	#
13	6.2	8.4	4.3	#	#	#	267	0.0	1050	#	#
14	2.0	5.7	-1.1	#	#	#	1038	0.0	750	#	#
15	-0.3	4.2	-2.6	#	#	#	1754	0.0	700	#	#
16	1.9	3.4	-2.5	#	#	#	323	0.0	1010	#	#
17	#	#	#	#	#	#	#	#	#	#	#
18	#	#	#	#	#	#	#	#	#	#	#
19	#	#	#	#	#	#	#	#	#	#	#
20	#	#	#	#	#	#	#	#	#	#	#
21	#	#	#	#	#	#	#	#	#	#	#
22	#	#	#	#	#	#	#	#	#	#	#
23	#	#	#	#	#	#	#	#	#	#	#
24	#	#	#	#	#	#	#	#	#	#	#
25	#	#	#	#	#	#	#	#	#	#	#
26	#	#	#	#	#	#	#	#	#	#	#
27	#	#	#	#	#	#	#	#	#	#	#
28	#	#	#	#	#	#	#	#	#	#	#
29	#	#	#	#	#	#	#	#	#	#	#
30	-12.7	-18.1	-20.6	-17.7	-15.2	-19.5	1008	0.0	910	43.5	#
31	-18.2	-17.8	-16.9	-18.0	-17.0	-19.0	375	0.0	920	48.0	#

#.....NO DATA COLLECTED FOR THIS DATE

*.....SENSOR MALFUNCTIONING

NOTES....

RESULTS ARE DAILY AVERAGE OR TOTAL OF AVAILABLE DATA WITH TYPICAL
 SAMPLING FREQUENCY OF 8 SCANS DAILY BASED ON 8AM TO 8AM DAY.
 TEMPERATURES BELOW APPROXIMATELY -27 C ARE REPORTED AS -27 C +/-1

03-13-1985

TABLE B12

Molokai & Diamond Ltd

FILE #.....

KEY LAKE PROJECT
 MONITORING OF LAYERED URANIUM TAILINGS - PHASE I
 MONTHLY DATA SUMMARY - NOVEMBER 1984

	channel #2			channel #15			#11	#12	#13	#14	#15
DAY	AIR TEMPERATURE (deg C)			AIR TEMPERATURE (deg C)			RYDAN (W/m2/day)	PRECIP (mm)	FLOW (litres)	HUMIDITY (%)	WIND RUR
	av	max	min	av	max	min	total	total	total	av	km/d.
1	-19.3	-16.2	-22.2	-18.4	-15.6	-21.2	1404	0.0	830	47.2	#
2	-17.2	-13.1	-21.8	-16.7	-14.6	-21.0	855	0.0	840	47.8	#
3	-15.8	-12.0	-19.8	-14.9	-11.1	-18.9	807	0.0	570	48.0	#
4	-17.5	-14.5	-20.3	-16.8	-13.7	-19.4	1041	0.0	740	48.1	#
5	-14.2	-10.6	-21.6	-13.5	-9.8	-20.9	1149	0.0	750	48.1	#
6	-15.7	-15.0	-17.5	-15.0	-14.2	-16.2	691	0.0	590	48.6	#
7	-13.4	-12.5	-14.5	-12.8	-11.4	-14.1	325	0.0	560	48.6	#
8	-14.3	-9.8	-21.5	-13.4	-9.3	-20.7	933	0.0	120	48.8	#
9	-15.5	-11.5	-21.0	-14.7	-10.3	-20.0	1058	0.0	0	48.8	#
10	-9.8	-8.1	-12.6	-9.1	-7.2	-12.0	579	0.0	0	49.0	#
11	-17.0	-11.1	-16.6	-12.0	-10.1	-15.3	756	0.0	0	48.7	#
12	-18.4	-17.9	-19.1	-17.8	-17.1	-18.5	567	0.0	0	47.5	#
13	-18.1	-17.0	-19.1	-17.6	-16.5	-18.7	792	0.0	0	48.7	#
14	-19.4	-18.9	-20.3	-18.7	-17.8	-19.5	441	0.0	0	48.6	#
15	-24.6	-21.5	-27.0	-24.0	-21.1	-27.0	786	0.0	0	48.7	#
16	-26.9	-23.7	-27.0	-26.1	-23.2	-27.0	1212	0.0	0	48.0	#
17	-22.0	-17.2	-27.0	#	#	#	496	0.0	0	40.3	#
18	-19.8	-17.9	-21.9	#	#	#	747	0.0	0	40.3	#
19	-13.8	-12.1	-17.0	-26.9	-26.8	-27.0	2556	0.0	0	38.3	#
20	-7.9	-6.1	-11.6	-26.7	-26.5	-26.8	1701	0.0	0	35.9	#
21	#	#	#	#	#	#	#	#	#	#	#
22	-4.6	-2.1	-9.4	-4.1	-1.4	-9.0	591	0.0	0	53.1	408.1
23	-1.0	0.4	-3.1	0.1	1.4	-2.5	363	0.0	100	52.7	112.1
24	-5.9	-1.2	-10.9	-5.4	-0.3	-9.9	576	0.0	0	53.2	#
25	-11.3	-4.9	-16.8	-10.1	-3.0	-15.3	942	0.0	0	53.1	#
26	-13.4	-7.6	-17.8	-12.0	-5.8	-16.6	768	0.0	0	53.3	#
27	-13.8	-11.6	-19.0	-14.4	-8.8	-17.9	790	0.0	0	52.8	#
28	-15.7	-13.1	-20.4	-14.8	-12.2	-19.2	636	0.0	0	52.7	#
29	-16.4	-13.9	-18.7	-15.2	-12.8	-17.4	489	0.0	0	52.6	#
30	-18.8	-15.3	-22.1	-17.5	-13.4	-21.0	456	0.0	0	52.7	#

#.....NO DATA COLLECTED FOR THIS DATE

*.....SENSOR MALFUNCTIONING

NOTES....

RESULTS ARE DAILY AVERAGE OR TOTAL OF AVAILABLE DATA WITH TYPICAL
 SAMPLING FREQUENCY OF 8 SCANS DAILY BASED ON 0AM TO 8AM DAY.
 TEMPERATURES BELOW APPROXIMATELY -27 C ARE REPORTED AS -27 C +/-1

02-13-1985

TABLE B13

Knight & Pincold Ltd

FILE #. ALTWINK12

KEY LAKE PROJECT
MONITORING OF LAYERED URANIUM TAILINGS - PHASE 1
MONTHLY DATA SUMMARY - DECEMBER 1984

	channel #2			channel #15			#11	#12	#13	#14	#16
DAY	AIR TEMPERATURE (deg C)			AIR TEMPERATURE (deg C)			PYRAN (W/m2/day)	PRECIP (mm)	FLOW (litres)	HMDTY (%)	WIND RUN (km/dy)
	av	max	min	av	max	min	total	total	total	av	
1	-20.0	-17.0	-22.6	-18.9	-15.8	-21.4	339	0.0	0	52.4	#
2	-16.1	-13.6	-18.6	-15.2	-12.4	-17.7	240	0.0	0	52.3	#
3	-18.6	-15.2	-22.7	-17.7	-14.5	-21.7	282	0.0	0	52.4	#
4	-26.6	-21.0	-27.0	-26.1	-20.1	-27.0	915	0.0	0	52.1	#
5	#	#	#	#	#	#	#	#	#	#	#
6	#	#	#	#	#	#	#	#	#	#	#
7	-1.8	0.7	-7.6	-3.0	0.2	-9.3	789	0.0	100	38.6	334.5
8	-6.4	-4.3	-10.7	-8.4	-5.9	-12.4	369	0.0	150	#	167.7
9	-7.1	-5.2	-11.2	-8.8	-6.9	-13.1	363	0.0	140	#	319.2
10	-21.0	-7.5	-27.0	-22.3	-9.2	-27.0	279	0.0	80	#	239.4
11	-27.0	-27.0	-27.0	-27.0	-27.0	-27.0	618	0.0	80	#	134.7
12	-27.0	-25.0	-27.0	-27.0	-26.9	-27.0	363	0.0	20	#	159.3
13	-23.9	-21.9	-27.0	-27.0	-23.6	-27.0	573	0.0	10	#	282.0
14	-16.4	-10.7	-24.9	-13.3	-12.5	-26.9	282	0.0	50	#	379.2
15	-27.0	-25.4	-27.0	-27.0	-27.0	-27.0	555	0.0	0	#	210.3
16	-27.0	-27.0	-27.0	-27.0	-27.0	-27.0	579	0.0	0	#	206.1
17	-26.0	-22.5	-27.0	-27.0	-24.3	-27.0	555	0.0	0	#	355.2
18	-19.1	-15.4	-22.3	-21.0	-17.4	-24.1	372	0.0	0	#	384.3
19	-25.0	-20.3	-27.0	-26.7	-22.3	-27.0	711	0.0	0	#	260.4
20	-24.2	-21.5	-27.0	-25.7	-23.4	-27.0	324	0.0	0	#	308.4
21	-27.0	-27.0	-27.0	-27.0	-27.0	-27.0	558	0.0	0	#	701.5
22	-27.0	-27.0	-27.0	-27.0	-27.0	-27.0	519	0.0	0	#	387.9
23	-27.0	-27.0	-27.0	-27.0	-27.0	-27.0	450	0.0	0	#	519.0
24	-27.0	-27.0	-27.0	-27.0	-27.0	-27.0	552	0.0	0	#	263.1
25	-27.0	-27.0	-27.0	-27.0	-27.0	-27.0	573	0.0	0	#	121.2
26	-27.0	-27.0	-27.0	-27.0	-27.0	-27.0	282	0.0	0	#	196.5
27	-27.0	-27.0	-27.0	-27.0	-27.0	-27.0	483	0.0	0	#	170.1
28	-27.0	-27.0	-27.0	-27.0	-27.0	-27.0	465	0.0	0	#	222.0
29	-27.0	-27.0	-27.0	-27.0	-27.0	-27.0	441	0.0	0	#	333.6
30	-27.0	-27.0	-27.0	-27.0	-27.0	-27.0	519	0.0	0	#	271.3
31	-27.0	-27.0	-27.0	-27.0	-27.0	-27.0	558	0.0	0	#	235.8

#.....NO DATA COLLECTED FOR THIS DATE

+.....SENSOR MALFUNCTIONING

NOTES....

RESULTS ARE DAILY AVERAGE OR TOTAL OF AVAILABLE DATA WITH TYPICAL
SAMPLING FREQUENCY OF 9 SCANS DAILY BASED ON 9AM TO 9AM DAY.
TEMPERATURES BELOW APPROXIMATELY -27 C ARE REPORTED AS -27 C +/-1

03-19-1985

TABLE B14

Knight & Piesold Ltd

FILE #...NLRAIN01

KEY LAKE PROJECT
MONITORING OF LAYERED URANIUM TAILINGS - PHASE 1
MONTHLY DATA SUMMARY - JANUARY 1985

	channel #2			channel #15			#11	#12	#13	#14	#16
DAY	AIR TEMPERATURE (deg C)			AIR TEMPERATURE (deg C)			TYRAN (W/m2/day)	PRECIP (mm)	FLOW (litres)	HUMIDITY (%)	WIND RUN
	av	max	min	av	max	min	total	total	total	av	(km/day)
1	-22.0	-16.2	-27.0	-23.7	-18.1	-27.0	585	0.0	0	#	208.1
2	-5.7	0.2	-14.7	-7.5	-1.6	-16.7	375	0.0	0	#	145.1
3	-0.1	3.0	-5.8	-2.1	1.0	-7.7	246	0.0	0	#	468.1
4	-5.1	-3.3	-7.6	-6.9	-5.1	-9.4	309	0.0	0	#	247.1
5	-11.4	-7.5	-14.6	-13.2	-9.3	-16.5	168	0.0	0	#	375.1
6	-19.4	-8.8	-27.0	-20.8	-10.7	-27.0	492	0.0	0	#	180.1
7	-27.0	-27.0	-27.0	-27.0	-27.0	-27.0	657	0.0	40	#	33.1
8	-26.9	-22.5	-27.0	-27.0	-24.5	-27.0	1376	0.0	0	#	36.1
9	-26.3	-23.8	-27.0	-27.0	-25.7	-27.0	414	0.0	0	#	79.1
10	-19.7	-14.3	-26.0	-21.9	-16.2	-27.0	723	0.3	30	#	143.1
11	-13.0	-11.3	-14.0	-14.8	-13.4	-15.9	489	0.3	0	#	220.1
12	-10.4	-4.1	-15.0	-12.2	-5.8	-16.9	399	0.0	0	#	277.1
13	-20.7	-15.3	-24.0	-22.7	-17.2	-26.0	702	0.0	0	#	236.1
14	-17.7	-16.4	-20.8	-19.6	-18.3	-22.7	453	0.0	0	#	138.1
15	-16.5	-13.9	-18.6	-18.4	-15.8	-20.5	330	0.0	0	#	83.1
16	-21.5	-16.1	-27.0	-23.1	-18.1	-27.0	312	0.0	0	#	138.1
17	-27.0	-27.0	-27.0	-27.0	-27.0	-27.0	675	0.0	0	#	108.1
18	-27.0	-27.0	-27.0	-27.0	-27.0	-27.0	777	0.0	0	#	137.1
19	-27.0	-25.8	-27.0	-27.0	-27.0	-27.0	711	0.0	0	#	233.1
20	-20.2	-17.0	-24.8	-22.2	-18.9	-26.8	522	0.0	0	#	175.1
21	-16.8	-13.5	-23.0	-18.8	-15.3	-25.2	765	0.0	0	#	351.1
22	-10.6	-8.4	-14.3	-12.5	-10.3	-16.3	609	0.0	0	#	191.1
23	-12.9	-7.7	-23.2	-14.8	-9.6	-25.1	243	0.0	0	#	294.1
24	-25.9	-22.2	-27.0	-27.0	-23.5	-27.0	1032	0.0	0	#	176.1
25	-16.0	-10.5	-22.9	-18.0	-12.5	-25.0	309	0.0	0	#	373.1
26	-21.0	-16.6	-25.5	-23.0	-18.8	-27.0	654	0.0	0	#	232.1
27	-17.1	-14.6	-21.5	-19.1	-16.5	-23.5	396	0.0	0	#	234.1
28	-25.4	-21.3	-27.0	-26.6	-23.3	-27.0	420	0.0	0	#	182.1
29	-27.0	-27.0	-27.0	-27.0	-27.0	-27.0	834	0.0	0	#	196.1
30	-27.0	-27.0	-27.0	-27.0	-27.0	-27.0	660	0.0	0	#	161.1
31	-27.0	-27.0	-27.0	-27.0	-27.0	-27.0	711	0.0	0	#	187.1

#.....NO DATA COLLECTED FOR THIS DATE

*.....SENSOR MALFUNCTIONING

NOTES....

RESULTS ARE DAILY AVERAGE OR TOTAL OF AVAILABLE DATA WITH TYPICAL
SAMPLING FREQUENCY OF 8 SCANS DAILY BASED ON 0AM TO 0AM DAY.
TEMPERATURES BELOW APPROXIMATELY -27 C ARE REPORTED AS -27 C +/-1

03-17-1985

TABLE B15

Knight & Fields Ltd

FILE #...LFRAIN02

KEY LAKE PROJECT
MONITORING OF LAYERED URANIUM TAILINGS - PHASE 1
MONTHLY DATA SUMMARY - FEBRUARY 1985

	channel #2			channel #15			#11	#12	#13	#14	#16
DAY	AIR TEMPERATURE (deg C)			AIR TEMPERATURE (deg C)			PYRAN (W/m2/day)	PRECIP (mm)	FLOW (litres)	HUMIDITY (%)	WIND RUN (km/dv)
	av	max	min	av	max	min	total	total	total	av	
1	-27.0	-27.0	-27.0	-27.0	-27.0	-27.0	741	0.0	0	#	133.7
2	-27.0	-27.0	-27.0	-27.0	-27.0	-27.0	801	0.0	0	#	190.6
3	-25.7	-22.3	-27.0	-27.0	-24.6	-27.0	915	0.0	0	#	259.5
4	-25.6	-19.7	-27.0	-26.7	-21.9	-27.0	633	0.0	0	#	185.4
5	-27.0	-27.0	-27.0	-27.0	-27.0	-27.0	648	0.0	0	#	141.1
6	-27.0	-27.0	-27.0	-27.0	-27.0	-27.0	693	0.0	0	#	161.5
7	-27.0	-26.8	-27.0	-27.0	-27.0	-27.0	795	0.0	0	#	189.7
8	-25.2	-23.1	-27.0	-26.8	-25.1	-27.0	562	0.0	0	#	241.1
9	-24.8	-21.9	-27.0	-26.3	-23.7	-27.0	714	0.0	0	#	213.2
10	-27.0	-24.9	-27.0	-27.0	-27.0	-27.0	1014	0.0	0	#	232.5
11	-25.4	-21.2	-27.0	-26.7	-21.7	-27.0	1365	0.0	0	#	233.3
12	#	#	#	#	#	#	#	#	#	#	#
13	#	#	#	#	#	#	#	#	#	#	#
14	#	#	#	#	#	#	#	#	#	#	#
15	-17.9	-15.0	-21.1	-19.8	-16.9	-23.0	834	0.5	0	#	285.7
16	-25.6	-22.0	-27.0	-27.0	-24.1	-27.0	1488	0.0	0	#	299.6
17	-27.0	-25.7	-27.0	-27.0	-27.0	-27.0	1815	0.0	0	#	271.8
18	-22.8	-18.1	-27.0	-24.2	-19.9	-27.0	1485	0.0	0	#	292.0
19	-11.9	-4.6	-21.4	-13.8	-6.4	-23.4	1026	0.0	0	#	396.2
20	-25.0	-22.5	-27.0	-26.8	-24.6	-27.0	1731	0.0	0	#	171.9
21	-16.9	-12.3	-26.0	-18.9	-14.1	-27.0	1482	0.0	0	#	294.6
22	-25.8	-22.7	-27.0	-27.0	-24.7	-27.0	2649	0.0	0	#	287.7
23	-22.0	-20.5	-26.0	-24.0	-22.3	-27.0	1203	0.0	0	#	265.5
24	-23.5	-19.7	-27.0	-25.2	-20.9	-27.0	1653	0.0	0	#	127.5
25	-24.1	-19.3	-27.0	-26.0	-21.5	-27.0	2169	0.0	0	#	141.3
26	-9.8	-5.8	-18.1	-11.7	-7.6	-20.0	2238	0.0	0	#	421.8
27	-2.4	1.4	-9.4	-4.3	-0.4	-11.2	1218	1.5	0	#	520.0
28	-8.8	-5.6	-12.0	-10.9	-8.0	-13.9	2178	0.0	0	#	279.3

#.....NO DATA COLLECTED FOR THIS DATE

*.....SENSOR MALFUNCTIONING

NOTES....

RESULTS ARE DAILY AVERAGE OR TOTAL OF AVAILABLE DATA WITH TYPICAL
SAMPLING FREQUENCY OF 8 SCANS DAILY BASED ON 8AM TO 8AM DAY.
TEMPERATURES BELOW APPROXIMATELY -27 C ARE REPORTED AS -27 C +/-1

03-13-1985

TABLE B16

Project: S. Pilsbald Ltd

FILE: S. PLSB.D

KEY LANE PROJECT
 MONITORING OF LAYERS GRANULAR TAILINGS - PHASE 1
 MONTHLY DATA SUMMARY - MARCH 1988

DAY	channel #2			channel #12			#11	#12	#13	#14	#15
	AIR TEMPERATURE (deg C)			AIR TEMPERATURE (deg C)			PYRAN (W/m ² /day)	PRECIP (mm)	FLOW (litres)	WIND (%)	WIND (km/h)
	av	max	min	av	max	min	total	total	total	av	max
1	-18.5	-10.7	-26.8	-20.4	-12.7	-27.0	2160	0.0	0	#	261.7
2	-16.6	-12.8	-27.0	-18.4	-14.5	-27.0	2457	0.0	0	#	302.5
3	-11.9	-8.9	-15.8	-13.8	-11.0	-17.7	2121	0.0	0	#	192
4	-13.2	-7.4	-17.5	-15.2	-9.3	-19.4	2643	0.0	0	#	167.1
5	-11.1	-4.6	-19.4	-13.1	-6.5	-21.4	2514	0.0	0	#	121.1
6	-14.6	10.9	-16.6	-16.6	-12.7	-18.5	2355	0.0	0	#	172.7
7	-12.6	-4.5	-16.7	-14.7	-7.2	-18.7	2298	0.0	0	#	171
8	-5.2	1.6	-14.0	-7.4	-0.7	-16.1	2664	0.7	0	#	293.1
9	-4.9	1.2	-10.3	-7.0	-1.2	-12.3	2049	0.0	0	#	239.7
10	#	#	#	#	#	#	#	#	#	#	#
11	#	#	#	#	#	#	#	#	#	#	#
12	#	#	#	#	#	#	#	#	#	#	#
13	#	#	#	#	#	#	#	#	#	#	#
14	#	#	#	#	#	#	#	#	#	#	#
15	#	#	#	#	#	#	#	#	#	#	#
16	#	#	#	#	#	#	#	#	#	#	#
17	#	#	#	#	#	#	#	#	#	#	#
18	#	#	#	#	#	#	#	#	#	#	#
19	#	#	#	#	#	#	#	#	#	#	#
20	#	#	#	#	#	#	#	#	#	#	#
21	#	#	#	#	#	#	#	#	#	#	#
22	#	#	#	#	#	#	#	#	#	#	#
23	#	#	#	#	#	#	#	#	#	#	#
24	#	#	#	#	#	#	#	#	#	#	#
25	#	#	#	#	#	#	#	#	#	#	#
26	#	#	#	#	#	#	#	#	#	#	#
27	#	#	#	#	#	#	#	#	#	#	#
28	#	#	#	#	#	#	#	#	#	#	#
29	#	#	#	#	#	#	#	#	#	#	#
30	#	#	#	#	#	#	#	#	#	#	#
31	#	#	#	#	#	#	#	#	#	#	#

#.....NO DATA COLLECTED FOR THIS DATE

A.....SENSOR MALFUNCTIONING

NOTES....

RESULTS ARE DAILY AVERAGE OR TOTAL OF AVAILABLE DATA WITH TYPICAL SAMPLING FREQUENCY OF 8 SCANS DAILY BASED ON 8AM TO 8AM DAY.
 TEMPERATURES BELOW APPROXIMATELY -27 C ARE REPORTED AS -27 C +/-

03-13-1988

TABLE B17

MONTANA & FIDELITY LLC

FILE #1111TAIL10

KEY LAKE PROJECT
MONITORING OF LAYERED URANIUM TAILINGS - PHASE 1
MONTHLY DATA SUMMARY - OCTOBER 1999

DAY	channel #1 TAILINGS TEMP (deg C)			channel #3 TAILINGS TEMP (deg C)			channel #4 TAILINGS TEMP (deg C)			ch #5	ch #6	ch #7	ch #8	ch #9	ch #10
										(mm H2O)	(mm H2O)	(mm H2O)	(mm H2O)	(mm H2O)	(mm H2O)
	av	max	min	av	max	min	av	max	min						
1	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#
2	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#
3	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#
4	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#
5	#	#	#	4.5	13.9	-1.6	4.4	13.4	-1.4	1157.4	1333.5	#	#	#	#
6	#	#	#	2.4	4.9	-1.4	2.4	5.6	-1.4	1196.3	1279.0	#	#	#	#
7	#	#	#	10.1	14.7	2.9	10.1	14.9	3.1	1180.3	1304.0	#	#	#	#
8	#	#	#	13.3	20.5	6.1	13.4	20.5	6.2	1176.8	1353.9	#	#	#	#
9	#	#	#	14.1	22.1	8.3	14.3	21.9	8.3	1191.7	1356.2	#	#	#	#
10	#	#	#	13.7	20.2	8.4	13.8	20.3	8.4	1213.5	1401.5	#	#	#	#
11	#	#	#	10.6	12.3	9.6	10.8	12.3	9.8	1235.3	1461.7	#	#	#	#
12	#	#	#	9.6	11.6	6.1	9.7	11.7	6.3	1243.3	1453.7	#	#	#	#
13	#	#	#	6.0	8.8	4.1	6.1	8.4	4.3	1251.3	1437.8	#	#	#	#
14	#	#	#	2.0	6.3	-1.3	2.1	6.2	-1.1	1314.3	1475.4	#	#	#	#
15	#	#	#	-0.2	4.7	-2.9	-0.1	4.5	-2.8	1329.1	1475.6	#	#	#	#
16	#	#	#	1.3	2.7	-2.7	1.5	3.1	-2.7	1449.5	1671.9	#	#	#	#
17	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#
18	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#
19	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#
20	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#
21	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#
22	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#
23	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#
24	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#
25	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#
26	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#
27	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#
28	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#
29	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#
30	#	#	#	-19.3	-15.5	-20.9	-19.2	-15.3	-20.9	1051.6	1495.5	#	#	#	#
31	#	#	#	-19.8	-17.4	-20.0	-18.7	-17.1	-19.8	1034.8	1383.4	#	#	#	#

#.....NO DATA COLLECTED FOR THIS DATE

*.....SENSOR MALFUNCTIONING

NOTES....

RESULTS ARE DAILY AVERAGE OR TOTAL OF AVAILABLE DATA WITH TYPICAL
SAMPLING FREQUENCY OF 8 SCANS DAILY BASED ON 8AM TO 8AM DAY.
TEMPERATURES BELOW APPROXIMATELY -27 C ARE REPORTED AS -27 C +/-

07-17-1999

TABLE B18

Knight & Pissard Ltd

FILE #.....

KEY LAKE PROJECT
MONITORING OF LAYERED URANIUM TAILINGS - PHASE 1
MONTHLY DATA SUMMARY - NOVEMBER 1991

DAY	channel #1 TAILINGS TEMP (deg C)			channel #3 TAILINGS TEMP (deg C)			channel #4 TAILINGS TEMP (deg C)			ch #5	ch #6	ch #7	ch #8	ch #9	ch #10
										(mm H2O)	(mm H2O)	(mm H2O)	(mm H2O)	(mm H2O)	(mm H2O)
	av	max	min	av	max	min	av	max	min						
1	1	1	1	-18.7	-12.2	-22.3	-18.5	-11.6	-22.2	993.1	1379.6	#	#	#	#
2	1	1	1	-17.1	-15.3	-22.2	-16.9	-15.1	-22.1	929.1	1379.6	#	#	#	#
3	1	1	1	-15.8	-10.6	-20.2	-15.6	-10.1	-20.2	938.4	1403.4	#	#	#	#
4	1	1	1	-17.3	-13.7	-20.9	-17.2	-13.0	-20.7	970.3	1410.2	#	#	#	#
5	-10.7	-10.7	-10.7	-13.9	-10.8	-22.1	-13.6	-10.5	-22.0	910.9	1383.0	#	#	#	#
6	-14.6	-14.6	-14.6	-15.5	-14.3	-17.7	-15.2	-13.8	-17.4	959.1	1386.4	#	#	#	#
7	1	1	1	-13.5	-12.6	-14.7	-13.3	-12.2	-14.5	969.4	1386.0	#	#	#	#
8	-14.6	-9.3	-21.7	-14.3	-9.2	-21.8	-14.1	-8.9	-21.7	1230.6	1393.2	#	#	#	#
9	-14.7	-8.1	-21.0	-15.2	-9.0	-21.3	-14.8	-8.9	-21.1	1313.1	1396.6	#	#	#	#
10	-9.9	-8.1	-12.5	-10.0	-8.3	-12.9	-9.8	-8.1	-12.7	1326.9	1376.2	#	#	#	#
11	-12.6	-9.1	-16.4	-12.9	-10.1	-16.5	-12.7	-9.6	-16.2	1399.1	1383.0	#	#	#	#
12	-19.1	-17.4	-19.0	-19.3	-17.6	-19.3	-19.2	-17.4	-19.0	1415.3	1376.2	#	#	#	#
13	-17.3	-13.0	-19.1	-17.9	-14.7	-19.3	-17.4	-13.9	-19.3	1385.3	1359.2	#	#	#	#
14	-19.3	-19.2	-20.3	-19.5	-19.7	-20.4	-19.3	-19.4	-20.3	1395.3	1362.6	#	#	#	#
15	-23.3	-13.4	-27.0	-24.1	-19.6	-27.0	-23.3	-15.3	-27.0	1395.6	1410.2	#	#	#	#
16	-24.9	-14.7	-27.0	-26.2	-20.0	-27.0	-25.4	-17.0	-27.0	1405.9	1349.0	#	#	#	#
17	-21.2	-17.4	-27.0	-21.6	-17.5	-27.0	-21.3	-17.3	-27.0	1399.1	1321.8	#	#	#	#
18	-18.7	-13.4	-22.2	-19.9	-17.0	-22.3	-19.2	-16.3	-22.2	1405.9	1321.8	#	#	#	#
19	-13.0	-8.6	-17.1	-13.6	-11.9	-17.3	-13.5	-11.7	-17.0	1416.3	1345.6	#	#	#	#
20	-6.4	-3.5	-11.4	-5.9	-2.9	-11.7	-7.5	-5.8	-11.4	1691.3	1509.9	#	#	#	#
21	-2.9	-2.3	-4.7	4.9	4.9	4.8	7.9	8.0	7.8	1661.5	1710.9	#	#	#	#
22	-2.3	-1.7	-2.8	4.9	4.9	4.7	7.9	8.0	7.8	1636.3	1692.7	#	#	#	#
23	-1.0	-0.2	-1.6	4.6	4.7	4.5	7.8	7.9	7.6	1660.3	1461.3	-226.9	557.2	#	#
24	-2.4	-0.2	-4.9	4.6	4.6	4.5	1	1	1	1739.4	1342.2	-205.3	570.9	#	#
25	-5.7	-4.6	-7.8	4.5	4.5	4.4	1	1	1	1780.6	1335.4	-115.9	705.0	#	#
26	-7.0	-6.6	-7.5	4.5	4.5	4.4	1	1	1	1770.3	1349.0	-96.7	962.9	#	#
27	-7.2	-6.7	-7.6	4.4	4.5	4.3	1	1	1	1708.4	1359.2	-161.6	966.3	#	#
28	-5.8	-4.3	-6.9	4.3	4.3	4.3	1	1	1	1619.1	1359.2	-250.9	949.1	#	#
29	-4.5	-4.4	-4.8	4.3	4.3	4.2	1	1	1	1598.4	1376.2	-226.9	928.4	#	#
30	-4.5	-4.3	-4.9	4.2	4.3	4.1	1	1	1	1608.8	1372.8	-206.3	907.8	#	#

#.....NO DATA COLLECTED FOR THIS DATE

*.....SENSOR MALFUNCTIONING

NOTES.....

RESULTS ARE DAILY AVERAGE OR TOTAL OF AVAILABLE DATA WITH TYPICAL
SAMPLING FREQUENCY OF 9 SCANS DAILY BASED ON 8AM TO 8AM DAY.
TEMPERATURES BELOW APPROXIMATELY -27 C ARE REPORTED AS -27 C +/-1

03-19-1995

TABLE B19

PHASE 1 TAILINGS LEE

FILE #111LTAIL12

KEY LAKE PROJECT
MONITORING OF LAYERED URANIUM TAILINGS - PHASE 1
MONTHLY DATA SUMMARY - DECEMBER 1984

DAY	channel #1 TAILINGS TEMP (deg C)			channel #3 TAILINGS TEMP (deg C)			channel #4 TAILINGS TEMP (deg C)			ch #5	ch #6	ch #7	ch #8	ch #9	ch #10
										pore water pressure in tailings					
	av	max	min	av	max	min	av	max	min	(mm H2O)	(mm H2O)	(mm H2O)	(mm H2O)	(mm H2O)	(mm H2O)
1	-4.8	-4.6	-5.1	4.2	4.3	4.1	#	#	#	763.1	1199.9	-182.2	897.5	#	#
2	-4.5	-4.2	-4.9	4.1	4.2	4.0	#	#	#	690.9	1094.4	-230.3	973.4	#	#
3	-4.4	-4.2	-4.6	4.0	4.1	3.9	#	#	#	673.8	1125.0	-261.3	963.1	#	#
4	-7.4	-4.4	-10.4	4.0	4.0	3.9	#	#	#	660.0	1073.9	-195.7	839.1	#	#
5	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#
6	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#
7	-0.2	-0.1	-0.4	3.4	3.4	3.4	7.1	7.2	7.1	853.4	1048.9	-522.5	794.1	#	#
8	-1.5	-0.9	-2.5	3.4	3.4	3.3	7.1	7.1	7.0	767.5	1055.8	-477.8	760.0	#	#
9	-3.2	-2.7	-3.6	3.3	3.3	3.3	7.0	7.1	7.0	781.3	1045.5	-501.9	735.9	#	#
10	-3.9	-2.6	-5.5	3.3	3.4	3.2	7.0	7.0	7.0	760.6	1038.6	-433.1	725.9	#	#
11	-7.4	-6.1	-8.2	3.2	3.2	3.2	7.0	7.0	6.9	770.9	990.5	-440.0	687.8	#	#
12	-7.0	-6.4	-7.6	3.1	3.2	3.1	6.9	6.9	6.8	750.3	952.7	-446.9	667.2	#	#
13	-7.3	-6.0	-8.0	3.1	3.1	3.1	6.9	6.9	6.9	753.8	1031.8	-460.6	650.0	#	#
14	-4.3	-3.4	-5.5	3.1	3.2	3.1	6.9	7.0	6.8	750.3	1066.1	-611.9	646.6	#	#
15	-5.0	-4.0	-6.1	3.1	3.1	3.0	6.8	6.8	6.7	738.6	942.4	-354.1	622.5	#	#
16	-7.0	-6.4	-7.3	3.0	3.0	3.0	6.7	6.8	6.7	722.8	959.6	-340.3	598.4	#	#
17	-6.9	-6.3	-7.3	3.0	3.0	2.9	6.7	6.8	6.7	726.3	952.7	-488.1	591.6	#	#
18	-5.1	-4.3	-6.0	2.9	3.0	2.9	6.6	6.7	6.5	715.9	1024.9	-690.9	570.9	#	#
19	-4.5	-4.1	-5.0	2.9	3.0	2.9	6.7	6.8	6.6	674.7	1011.1	-653.1	546.9	#	#
20	-4.6	-4.3	-4.9	2.9	3.0	2.8	6.6	6.7	6.6	650.6	1018.0	-697.8	540.0	#	#
21	-5.7	-4.8	-6.2	2.8	2.9	2.8	6.5	6.6	6.5	636.9	987.1	-611.9	526.3	#	#
22	-6.6	-6.1	-7.3	2.9	2.9	2.8	6.6	6.6	6.5	643.8	1186.4	-649.7	515.9	#	#
23	-8.3	-7.6	-8.9	2.9	3.0	2.9	6.5	6.6	6.5	626.6	1196.8	-721.9	491.9	#	#
24	-9.3	-9.1	-9.5	2.8	2.9	2.8	6.5	6.6	6.4	592.2	967.0	-653.1	460.9	#	#
25	-9.9	-9.6	-10.2	2.7	2.8	2.7	6.4	6.4	6.4	550.9	866.8	-492.4	457.5	#	#
26	-8.9	-7.9	-10.1	2.7	2.8	2.7	6.4	6.4	6.3	592.2	842.7	-594.7	419.7	#	#
27	-8.0	-7.9	-8.2	2.7	2.7	2.6	6.3	6.3	6.3	513.1	825.5	-618.4	402.5	#	#
28	-8.5	-8.3	-8.7	2.6	2.7	2.6	6.3	6.3	6.2	550.9	849.6	-639.1	402.5	#	#
29	-8.6	-8.3	-8.9	2.6	2.6	2.6	6.3	6.3	6.2	499.4	859.9	-704.7	388.8	#	#
30	-7.9	-7.6	-8.2	2.6	2.6	2.5	6.2	6.2	6.2	520.0	794.6	-646.3	399.1	#	#
31	-7.5	-7.4	-7.6	2.5	2.5	2.5	6.2	6.2	6.1	506.3	770.5	-666.9	371.6	#	#

#.....NO DATA COLLECTED FOR THIS DATE

#.....SENSOR MALFUNCTIONING

NOTES....

RESULTS ARE DAILY AVERAGE OR TOTAL OF AVAILABLE DATA WITH TYPICAL
SAMPLING FREQUENCY OF 8 SCANS DAILY BASED ON 8AM TO 8AM DAY.
TEMPERATURES BELOW APPROXIMATELY -27 C ARE REPORTED AS -27 C +/-1

01-19-1985

TABLE B20

INVESTIGATION REPORT

DATE: 01/17/1985

KEY LAKE PROJECT
MONITORING OF LAYERED URANIUM TAILINGS - PHASE 1
MONTHLY DATA SUMMARY - JANUARY 1985

DAY	channel #1 TAILINGS TEMP			channel #3 TAILINGS TEMP			channel #4 TAILINGS TEMP			ch #5	ch #6	ch #7	ch #8	ch #9	ch #11
	(deg C)			(deg C)			(deg C)			in	in	in	in	in	in
	av	max	min	av	max	min	av	max	min	H2O	H2O	H2O	H2O	H2O	H2O
1	-6.8	-6.1	-7.4	2.5	2.5	2.4	6.1	6.2	6.1	513.1	791.1	-779.1	747.5	#	#
2	-4.5	-3.1	-5.8	2.5	2.5	2.4	6.1	6.2	6.1	537.2	828.9	-807.9	764.7	#	#
3	-1.9	-1.5	-2.7	2.5	2.5	2.4	6.1	6.1	6.0	405.5	665.8	-775.9	721.9	#	#
4	-1.9	-1.5	-2.7	2.4	2.4	2.3	6.0	6.0	6.0	444.4	811.8	-708.1	761.3	#	#
5	-1.5	-1.5	-1.6	2.3	2.4	2.3	6.0	6.0	6.0	492.5	753.3	-755.3	747.5	#	#
6	-1.5	-1.5	-1.6	2.4	2.4	2.3	6.0	6.0	5.9	437.5	770.5	-673.8	740.5	#	#
7	-1.9	-1.6	-2.0	2.3	2.5	2.2	5.9	6.1	5.9	513.1	1007.7	-537.4	727.4	#	#
8	-2.3	-2.1	-2.5	2.2	2.3	2.2	5.9	6.0	5.9	580.7	1097.3	-569.5	704.0	#	#
9	-2.9	-2.5	-3.9	2.3	2.3	2.2	5.9	6.0	5.9	499.4	1179.6	-536.3	704.0	#	#
10	-5.1	-4.4	-5.5	2.3	2.5	2.2	5.9	6.1	5.8	447.8	1189.9	-530.9	#	#	#
11	-4.5	-3.9	-5.3	2.2	2.2	2.1	5.9	5.9	5.8	530.3	909.0	-718.4	-467.3	#	#
12	-3.1	-2.7	-3.6	2.1	2.2	2.1	5.8	5.8	5.8	495.9	756.8	-842.2	-610.9	#	#
13	-2.4	-2.3	-2.5	2.1	2.2	2.1	5.8	5.8	5.8	765.3	877.1	-715.0	-507.6	#	#
14	-2.6	-2.6	-2.7	2.1	2.1	2.0	5.8	5.8	5.7	416.9	937.4	-735.6	-545.6	#	#
15	-2.4	-2.3	-2.6	2.1	2.1	2.0	5.7	5.8	5.7	416.9	956.4	-763.1	-575.6	#	#
16	-2.2	-2.2	-2.3	2.1	2.1	2.0	5.7	5.7	5.7	420.3	880.5	-770.0	-583.4	#	#
17	-2.6	-2.3	-2.9	2.0	2.1	2.0	5.7	5.7	5.6	392.8	863.3	-783.8	-575.3	#	#
18	-3.5	-3.1	-3.9	2.0	2.0	2.0	5.6	5.7	5.6	337.8	966.4	-660.0	-442.5	#	#
19	-4.3	-4.0	-4.4	2.0	2.0	1.9	5.6	5.7	5.6	327.5	1107.4	-546.6	-411.5	#	#
20	-4.1	-3.7	-4.4	2.0	2.0	1.9	5.6	5.6	5.5	369.8	1076.4	-570.6	-528.4	#	#
21	-3.2	-2.9	-3.5	1.9	1.9	1.9	5.5	5.6	5.5	389.4	942.4	-708.1	-565.9	#	#
22	-2.6	-2.3	-2.9	1.9	1.9	1.9	5.5	5.5	5.5	782.5	825.5	-600.9	-762.8	#	#
23	-2.0	-1.9	-2.2	1.9	2.0	1.8	5.5	5.5	5.5	320.6	828.9	-845.6	-934.4	#	#
24	-2.1	-1.9	-2.3	1.9	1.9	1.8	5.5	5.5	5.4	324.1	887.4	-728.8	-751.9	#	#
25	-2.5	-2.4	-2.6	1.8	1.9	1.8	5.5	5.5	5.4	416.9	825.5	-571.9	-375.6	#	#
26	-2.4	-2.3	-2.5	1.8	1.9	1.8	5.4	5.5	5.4	324.1	863.3	-790.6	-920.3	#	#
27	-2.5	-2.4	-2.5	1.8	1.9	1.8	5.4	5.5	5.4	327.5	849.6	-814.7	-954.7	#	#
28	-2.5	-2.4	-2.6	1.8	1.9	1.8	5.4	5.4	5.3	324.1	849.6	-875.2	-910.0	#	#
29	-3.2	-2.8	-3.6	1.8	1.8	1.8	5.4	5.4	5.3	303.4	969.9	-728.8	-900.0	#	#
30	-4.0	-3.7	-4.2	1.8	1.8	1.8	5.3	5.4	5.3	317.2	963.0	-749.4	-896.3	#	#
31	-4.2	-4.2	-4.3	1.8	1.8	1.7	5.3	5.4	5.3	300.0	966.4	-759.7	-940.9	#	#

#.....NO DATA COLLECTED FOR THIS DATE

#.....SENSOR MALFUNCTIONING

NOTES....

RESULTS ARE DAILY AVERAGE OR TOTAL OF AVAILABLE DATA WITH TYPICAL
SAMPLING FREQUENCY OF 8 SCANS DAILY BASED ON 8AM TO 8AM DAY.
TEMPERATURES BELOW APPROXIMATELY -27 C ARE REPORTED AS -27 C +/- 1

03-17-1985

TABLE B21

KEY LAKE PROJECT
MONITORING OF LAYERED URANIUM TAILINGS - PHASE 1
MONTHLY DATA SUMMARY - FEBRUARY 1985

DAY	channel #1			channel #3			channel #4			ch #5	ch #6	ch #7	ch #8	ch #9	ch #10
	TAILINGS TEMP			TAILINGS TEMP			TAILINGS TEMP			pore water pressure in tailings					
	(deg C)			(deg C)			(deg C)			(m)	(m)	(m)	(m)	(m)	(m)
	av	max	min	av	max	min	av	max	min	H2O1	H2O2	H2O3	H2O4	H2O5	H2O6
1	-4.4	-4.3	-4.5	1.9	1.9	1.7	5.2	5.2	5.2	210.2	291.2	-825.0	-858.4	0	0
2	-4.5	-4.5	-4.7	1.7	1.9	1.7	5.2	5.2	5.2	222.5	319.3	-813.1	-851.2	0	0
3	-4.5	-4.5	-4.7	1.7	1.7	1.6	5.2	5.2	5.2	258.8	334.4	-825.2	-1009.7	0	0
4	-4.3	-4.1	-4.5	1.7	1.7	1.7	5.2	5.2	5.1	300.0	767.5	-845.2	-1081.9	0	0
5	-4.2	-4.1	-4.2	1.7	1.7	1.6	5.2	5.2	5.1	279.4	829.4	-876.5	-1009.7	0	0
6	-4.3	-4.2	-4.3	1.7	1.7	1.6	5.1	5.2	5.1	279.4	901.5	-794.1	-955.0	0	0
7	-4.4	-4.4	-4.5	1.7	1.7	1.6	5.1	5.2	5.1	248.4	970.2	-749.4	-1005.2	0	0
8	-4.3	-4.1	-4.5	1.6	1.6	1.6	5.1	5.2	5.0	248.4	915.1	-770.0	-1081.9	0	0
9	-3.9	-3.9	-4.0	1.6	1.6	1.6	5.1	5.1	5.0	241.6	887.8	-849.1	-1130.0	0	0
10	-4.1	-3.9	-4.2	1.6	1.6	1.5	5.0	5.1	5.0	231.2	901.5	-823.4	-1105.9	0	0
11	-4.4	-4.2	-4.5	1.6	1.7	1.5	5.1	5.2	5.0	232.1	630.6	-911.2	-1198.3	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	-3.6	-3.4	-3.7	1.5	1.5	1.5	4.9	5.0	4.9	258.8	698.4	-1055.3	-1391.2	0	0
16	-3.1	-2.9	-3.3	1.5	1.5	1.4	4.9	5.0	4.9	207.2	777.3	-1007.2	-1325.9	0	0
17	-2.9	-2.9	-3.0	1.5	1.5	1.4	4.9	4.9	4.9	203.6	846.5	-924.7	-1231.2	0	0
18	-3.1	-3.0	-3.1	1.5	1.5	1.4	4.9	4.9	4.8	231.2	757.5	-962.5	-1315.5	0	0
19	-3.0	-2.8	-3.1	1.4	1.5	1.4	4.8	4.9	4.8	242.0	632.4	-1079.4	-1387.3	0	0
20	-2.5	-2.5	-2.5	1.5	1.5	1.4	4.8	4.9	4.8	192.4	764.1	-990.0	-1331.9	0	0
21	-2.6	-2.5	-2.6	1.4	1.5	1.4	4.8	4.8	4.8	210.6	681.6	-1027.8	-1339.7	0	0
22	-2.5	-2.5	-2.6	1.4	1.4	1.4	4.8	4.8	4.7	159.1	846.5	-887.4	-1291.5	0	0
23	-2.6	-2.5	-2.7	1.4	1.4	1.3	4.7	4.8	4.7	224.4	784.7	-910.9	-1332.5	0	0
24	-2.5	-2.5	-2.7	1.3	1.4	1.3	4.7	4.8	4.7	200.3	777.3	-925.0	-1322.5	0	0
25	-2.6	-2.5	-2.6	1.4	1.4	1.3	4.7	4.8	4.7	187.1	862.8	-878.8	-1328.9	0	0
26	-2.5	-2.5	-2.6	1.3	1.4	1.3	4.7	4.7	4.6	231.2	732.1	-962.5	-1411.5	0	0
27	-2.2	-2.1	-2.3	1.3	1.4	1.3	4.7	4.7	4.6	227.3	602.5	-1095.5	-1470.2	0	0
28	-1.9	-1.5	-2.0	1.3	1.4	1.3	4.7	4.7	4.6	175.2	688.4	-1051.9	-1370.5	0	0

#.....NO DATA COLLECTED FOR THIS DATE

*.....SENSOR MALFUNCTIONING

NOTES....

RESULTS ARE DAILY AVERAGE OR TOTAL OF AVAILABLE DATA WITH TYPICAL SAMPLING FREQUENCY OF 8 SCANS DAILY BASED ON BAM TO BAM DAY. TEMPERATURES BELOW APPROXIMATELY -27 C ARE REPORTED AS -27 C +/-

03-13-1985

TABLE B22

NOV LIME PROJECT
 MONITORING OF LAYERED URANIUM TAILINGS - PART 2
 MONTHLY DATA SUMMARY - MARCH 1999

DAY	channel #1 TAILINGS TEMP			channel #3 TAILINGS TEMP			channel #4 TAILINGS TEMP			ch #5	ch #6	ch #7	ch #8	ch #9	ch #10
	TAILINGS TEMP			TAILINGS TEMP			TAILINGS TEMP			core water pressure at tailings	core water pressure at tailings	core water pressure at tailings	core water pressure at tailings	core water pressure at tailings	core water pressure at tailings
	(deg C)	(deg C)	(deg C)	(deg C)	(deg C)	(deg C)	(deg C)	(deg C)	(deg C)	(kPa)	(kPa)	(kPa)	(kPa)	(kPa)	(kPa)
1	-1.6	-1.8	-1.6	1.3	1.3	1.3	4.6	4.6	4.6	159.1	253.4	-122.4	-1240.1	0	0
2	-1.5	-1.6	-2.1	1.3	1.3	1.3	4.6	4.6	4.6	207.2	201.6	-125.3	-1219.4	0	0
3	-2.1	-2.1	-2.2	1.3	1.3	1.2	4.6	4.6	4.6	227.2	227.4	-122.5	-1224.2	0	0
4	-2.1	-2.0	-2.1	1.3	1.3	1.2	4.6	4.6	4.6	195.9	219.6	-121.4	-1212.2	0	0
5	-2.1	-2.0	-2.2	1.3	1.3	1.2	4.6	4.6	4.6	214.1	208.6	-122.2	-1216.2	0	0
6	-2.1	-2.0	-2.1	1.3	1.3	1.2	4.6	4.6	4.6	224.4	240.1	-122.6	-1222.2	0	0
7	-2.1	-2.0	-2.1	1.3	1.3	1.2	4.6	4.6	4.6	207.2	229.1	-122.6	-1222.6	0	0
8	-2.0	-1.9	-2.0	1.3	1.4	1.2	4.6	4.7	4.6	210.6	226.2	-122.6	-1222.6	0	0
9	-1.7	-1.6	-1.9	1.3	1.4	1.2	4.6	4.6	4.4	207.2	228.1	-121.8	-1222.4	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

#.....NO DATA COLLECTED FOR THIS DATE

#.....SENSOR MALFUNCTIONING

NOTES....

RESULTS ARE DAILY AVERAGE OR TOTAL OF AVAILABLE DATA WITH TYPICAL
 SAMPLING FREQUENCY OF 8 SCANS DAILY BASED ON 6AM TO 6AM DAY.
 TEMPERATURES BELOW APPROXIMATELY -27 C ARE REPORTED AS -27 C (-1)

03-17-1999

TABLE B23

KEY LAKE PROJECT
MONITORING OF LAYERED URANIUM TAILINGS - PHASE I

STANDPIPE WATER ELEVATIONS - SITE A

ELEVATION OF HDPE LINER = 539.6 METRES

<u>Date</u>		<u>STANDPIPE NUMBERS</u>			
		SP1-A	SP2-A	SP3-A	SP4-A
November 22	Water Elevation (m)	540.19	540.22	540.21	540.19
	Depth (m)	0.71	0.71	0.69	0.58
December 5	Water Elevation (m)	539.94	539.95	540.17	539.96
	Depth (m)	0.46	0.44	0.65	0.35
December 7	Water Elevation (m)	539.90	539.82	539.93	539.90
	Depth (m)	0.42	0.31	0.41	0.29
January 7	Water Elevation (m)*	539.6	539.6	539.6	539.7
	Depth (m)	DRY	DRY	DRY	DRY
February 11	Water Elevation (m)*	539.6	539.6	539.6	539.6
	Depth (m)	DRY	DRY	DRY	DRY
March 10		DRY	DRY	DRY	DRY

* Phreatic Surface is less than or equal to these values.

Depth is approximate elevation of phreatic surface above HDPE liner under Site A.

TABLE B24

KEY LAKE PROJECT
MONITORING OF LAYERED URANIUM TAILINGS - PHASE I

TEMPERATURE IN AND ABOVE TAILINGS SITE B
INITIAL TAILINGS DEPTH = 1.2 METRES ABOVE FILTER

Date	<u>Sensor Elevation Above Filter (m)</u>			
	0.2	0.8	1.4	2.0
	Temperature		°C	
October 5	6.4	4.5	2.4	2.8
October 16	7.8	6.2	0.1	0.5
October 29	5.0	2.7	-8.0	-13.4
November 22	3.3	1.2	-2.1	-4.1
January 10	1.5	0.0	-1.9	-22.6
February 12	1.2	0.0	0.0*	-9.2*
February 14	1.4	0.0	0.0*	-10.4*
March 10	1.2	+0.1	0.0	-1.2*(+11.2)**

Notes:

Prior to February 12 Sensor 1.4 was approximately 200 mm and Sensor 2.0, 800 mm above tailings.

* Additional 600 mm of frozen material at site deposited between January 10 and February 12.

** +11.2°C temperature (falling steadily) was observed March 9th.

TABLE B25

Knight & Piesold Ltd
KEY LAKE PROJECT
MONITORING OF LAYERED URANIUM TAILINGS - PHASE 1
MOISTURE & DENSITY CALCULATED FROM CORE SAMPLES

MOISTURE-DENSITY PROBE.....CALIBRATION CORES.....OCT 1984

assumed solids specific gravity = 2.64 gm/cc

SAMPLE	TARE	TOTWET	TOTDRY	WET	DRY	WATER	CALCVOL	SOLID	WATER	M/C	PORE	DRYDEN	BLKDN
#	(gm)	(gm)	(gm)	(gm)	(gm)	(gm)	(cc)	(%)	(%)	(%)	(m3/m3)	(t/m3)	(t/m3)
SITE B	38.9	427.1	211.7	388.2	172.8	215.4	280.9	44.5	55.5	124.7	0.767	0.615	1.382
WET DRUM	29.4	637.6	388.5	608.4	359.1	249.3	385.3	59.0	41.0	69.4	0.647	0.932	1.579
DRY DRUM	39.1	505.3	382.0	466.2	342.9	123.3	253.2	73.6	26.4	36.0	0.487	1.354	1.841
DRYBEACH	38.2	4245.7	3133.0	4207.5	3094.8	1112.7	2285.0	73.6	26.4	36.0	0.487	1.354	1.841

NOTES.....

ALL CALCULATIONS ASSUME THAT SAMPLES ARE COMPLETELY SATURATED
 CALCVOL = WATER VOL + (DRY WGT SOLIDS/SPECIFIC GRAVITY SOLIDS)
 PORE = WATER LOSS/((WATER LOSS + (DRY WGT/SOLIDS S.G.))
 DRYDEN = DRY WEIGHT/((WATER LOSS + (DRY WGT/SOLIDS S.G.))
 BLKDN = WET WEIGHT/((WATER LOSS + (DRY WGT/SOLIDS S.G.))

FILE NAME.. coresoct.84

DATE..... 03-13-1985

TABLE B26

Knight & Piesold Ltd
KEY LAKE PROJECT
MONITORING OF LAYERED URANIUM TAILINGS - PHASE 1
MOISTURE & DENSITY CALCULATED FROM CORE SAMPLES

SITE A.....AUGERED SAMPLE.....JAN 11 1985

assumed solids specific gravity = 2.64 gm/cc

SAMPLE	TARE	TOTWET	TOTDRY	WET	DRY	WATER	CALCVOL	SOLID	WATER	M/C	PORE	DRYDEN	BLKDEN
#	(gm)	(gm)	(gm)	(gm)	(gm)	(gm)	(cc)	(%)	(%)	(%)	(m3/m3)	(t/m3)	(t/m3)
1-460mm	20.3	400.9	178.3	380.6	158.0	222.6	282.4	41.5	59.5	140.9	0.788	0.559	1.347
2-550mm	20.1	509.3	196.9	489.2	176.8	312.4	379.4	36.1	63.9	176.7	0.823	0.466	1.290
3-700mm	20.7	815.7	306.6	795.0	285.9	509.1	617.4	36.0	64.0	178.1	0.825	0.463	1.288
4-900mm	20.1	649.0	221.2	628.9	201.1	427.8	504.0	32.0	68.0	212.8	0.849	0.399	1.248
5-1150mm	10.1	595.0	205.8	584.9	195.7	389.2	463.3	33.5	66.5	198.9	0.840	0.422	1.262
AVERAGE.....				2878.5	1017.4	1861.1	2246.5	35.3	64.7	182.9	0.828	0.453	1.281

NOTES.....

ALL CALCULATIONS ASSUME THAT SAMPLES ARE COMPLETELY SATURATED
 CALCVOL = WATER VOL + (DRY WGT SOLIDS/SPECIFIC GRAVITY SOLIDS)
 PORE = WATER LOSS/((WATER LOSS + (DRY WGT/SOLIDS S.G.))
 DRYDEN = DRY WEIGHT/((WATER LOSS + (DRY WGT/SOLIDS S.G.))
 BLKDEN = WET WEIGHT/((WATER LOSS + (DRY WGT/SOLIDS S.G.))

FILE NAME.. CORES.JAN.11
 DATE..... 03-12-1985

TABLE B27

Knight & Piesold Ltd
KEY LAKE PROJECT
MONITORING OF LAYERED URANIUM TAILINGS - PHASE 1
MOISTURE & DENSITY CALCULATED FROM CORE SAMPLES

site A.....core samples.....feb 11-15 1985

assumed solids specific gravity = 2.64 gm/cc

SAMPLE #	TARE (gm)	TOTWET (gm)	TOTDRY (gm)	WET (gm)	DRY (gm)	WATER (gm)	CALCVOL (cc)	SOLID (Z)	WATER (Z)	M/C (Z)	PORE (m3/m3)	DRYDEN (t/m3)	BLKDEN (t/m3)
1-1	9.4	280.5	95.6	271.1	86.2	184.9	217.6	31.8	68.2	214.5	0.850	0.396	1.246
AVERAGE.....				271.1	86.2	184.9	217.6	31.8	68.2	214.5	0.850	0.396	1.246
1-2-1	9.5	150.4	55.8	140.9	46.3	94.6	112.1	32.9	67.1	204.3	0.844	0.413	1.256
1-2-2	9.5	151.5	60.9	142.0	51.4	90.6	110.1	36.2	63.8	176.3	0.823	0.467	1.290
1-2-3	9.5	114.2	46.4	104.7	36.9	67.8	81.8	35.2	64.8	183.7	0.829	0.451	1.280
1-2-4	6.3	107.2	45.6	100.9	39.3	61.6	76.5	38.9	61.1	156.7	0.805	0.514	1.319
AVERAGE.....				488.5	173.9	314.6	380.5	35.6	64.4	180.9	0.827	0.457	1.284
2-2	9.7	794.4	262.5	784.7	252.8	531.9	627.7	32.2	67.8	210.4	0.847	0.403	1.250
AVERAGE.....				784.7	252.8	531.9	627.7	32.2	67.8	210.4	0.847	0.403	1.250
2-3-1	6.3	140.6	45.6	134.3	39.3	95.0	109.9	29.3	70.7	241.8	0.865	0.358	1.222
2-3-2	9.5	153.1	53.5	143.6	44.0	99.6	116.3	30.6	69.4	226.4	0.857	0.378	1.235
2-3-3	9.5	152.0	55.1	142.5	45.6	96.9	114.2	32.0	68.0	212.5	0.849	0.399	1.248
2-3-4	6.3	153.6	51.7	147.3	45.4	101.9	119.1	30.8	69.2	224.4	0.856	0.381	1.237
2-3-5	9.5	221.5	81.4	212.0	71.9	140.1	167.3	33.9	66.1	194.9	0.837	0.430	1.267
AVERAGE.....				779.7	246.2	533.5	626.8	31.6	68.4	216.7	0.851	0.393	1.244
2-4-1	6.3	138.9	45.1	132.6	38.8	93.8	108.5	29.3	70.7	241.8	0.865	0.358	1.222
2-4-2	9.5	147.0	50.6	137.5	41.1	96.4	112.0	29.9	70.1	234.5	0.861	0.367	1.228
2-4-3	6.3	148.7	54.1	142.4	47.8	94.6	112.7	33.6	66.4	197.9	0.839	0.424	1.263
2-4-4	6.3	148.7	49.9	142.4	43.6	98.8	115.3	30.6	69.4	226.6	0.857	0.378	1.235
2-4-5	9.5	182.2	70.6	178.7	61.1	117.6	140.7	34.2	65.8	192.5	0.836	0.434	1.270
AVERAGE.....				733.6	232.4	501.2	589.2	31.7	68.3	215.7	0.851	0.394	1.245
3-1-1	6.3	151.5	52.1	145.2	45.8	99.4	116.7	31.5	68.5	217.0	0.851	0.392	1.244
3-1-2	6.3	140.2	49.4	133.9	43.1	90.8	107.1	32.2	67.8	210.7	0.848	0.402	1.250
3-1-3	9.5	168.8	61.5	159.3	52.0	107.3	127.0	32.6	67.4	206.3	0.845	0.409	1.254
3-1-4	9.5	207.3	83.5	197.8	74.0	123.8	151.8	37.4	62.6	167.3	0.815	0.487	1.303
AVERAGE.....				636.2	214.9	421.3	502.7	33.8	66.2	196.0	0.838	0.427	1.266
3-2	9.5	370.4	125.2	360.9	115.7	245.2	289.0	32.1	67.9	211.9	0.848	0.400	1.249
AVERAGE.....				360.9	115.7	245.2	289.0	32.1	67.9	211.9	0.848	0.400	1.249
3-3-1	9.5	139.4	45.6	129.9	36.1	93.8	107.5	27.8	72.2	259.8	0.873	0.336	1.209
3-3-2	6.3	146.4	51.1	140.1	44.2	95.3	112.3	32.0	68.0	212.7	0.849	0.399	1.248
3-3-3	9.5	153.7	61.0	144.2	51.5	92.7	112.2	35.7	64.3	180.0	0.826	0.459	1.285
3-3-4	6.3	144.5	51.1	138.2	44.8	93.4	110.4	32.4	67.6	208.5	0.846	0.406	1.252
3-3-5	9.5	132.0	55.5	122.5	46.0	76.5	93.9	37.6	62.4	166.3	0.814	0.490	1.304
AVERAGE.....				674.9	223.2	451.7	536.2	33.1	66.9	202.4	0.842	0.416	1.259

Knight & Piesold Ltd
KEY LAKE PROJECT
MONITORING OF LAYERED URANIUM TAILINGS - PHASE 1
MOISTURE & DENSITY CALCULATED FROM CORE SAMPLES

SITE A....UNDISTURBED CORES TAKEN MARCH 8/9/10 1985

assumed solids specific gravity = 2.64 gm/cc

SAMPLE #	TARE (gm)	TOTWET (gm)	TOTDRY (gm)	WET (gm)	DRY (gm)	WATER (gm)	CALCVOL (cc)	SOLID (%)	WATER (%)	M/C (%)	PORE (m3/m3)	DRYDEN (t/m3)	BLKDEN (t/m3)
1-1-1BOT	9.5	138.5	48.2	129.0	38.7	90.3	105.0	30.0	70.0	233.6	0.860	0.368	1.229
1-1-2	9.5	152.1	56.4	142.5	46.8	95.7	113.4	32.9	67.1	204.4	0.844	0.413	1.256
1-1-3	9.5	147.9	60.4	138.3	50.8	87.5	106.8	36.7	63.3	172.2	0.820	0.476	1.296
1-1-4TOP	9.5	154.2	67.6	144.7	58.0	86.6	108.6	40.1	59.9	149.2	0.798	0.534	1.332
AVERAGE.....				554.5	194.4	360.2	433.8	35.0	65.0	185.3	0.830	0.448	1.278
1-2-1BOT	9.5	223.5	78.6	214.0	69.1	144.9	171.0	32.3	67.7	209.5	0.847	0.404	1.251
1-2-2	9.5	156.0	70.3	146.5	60.7	85.8	108.8	41.5	58.5	141.2	0.788	0.558	1.347
1-2-3TOP	9.5	158.4	74.6	148.9	65.1	83.7	108.4	43.7	56.3	128.6	0.772	0.601	1.373
AVERAGE.....				509.4	195.0	314.4	388.2	38.3	61.7	161.2	0.810	0.502	1.312
1-3-1BOT	9.5	148.7	55.0	139.1	45.5	93.6	110.9	32.7	67.3	205.8	0.845	0.410	1.255
1-3-2	9.5	151.7	65.4	142.2	55.9	86.3	107.5	39.3	60.7	154.6	0.803	0.520	1.323
1-3-3TOP	9.5	159.5	72.1	150.0	62.5	87.4	111.1	41.7	58.3	139.8	0.787	0.563	1.350
AVERAGE.....				431.3	163.9	267.4	329.5	38.0	62.0	163.2	0.812	0.497	1.309
2-1-1BOT	6.2	152.9	65.2	146.7	59.0	87.8	110.1	40.2	59.8	148.8	0.797	0.536	1.333
2-1-2	6.2	151.3	63.3	145.1	57.1	88.0	109.6	39.3	60.7	154.3	0.803	0.520	1.323
2-1-3	9.5	152.7	59.8	143.2	50.3	92.8	111.9	35.2	64.8	184.4	0.830	0.450	1.279
2-1-4TOP	9.5	164.5	75.1	155.0	65.6	89.4	114.2	42.3	57.7	136.2	0.782	0.575	1.357
AVERAGE.....				590.0	232.0	358.0	445.8	39.3	60.7	154.3	0.803	0.520	1.323
2-2-1BOT	6.2	184.8	110.9	178.6	104.7	73.9	113.6	58.6	41.4	70.6	0.651	0.922	1.573
2-2-2	6.2	153.5	59.2	147.3	53.0	94.3	114.4	36.0	64.0	178.1	0.825	0.463	1.288
2-2-3	9.5	146.9	51.4	137.4	41.9	95.6	111.4	30.5	69.5	228.3	0.858	0.376	1.233
2-2-4TOP	6.2	139.1	76.4	132.9	70.2	62.7	89.3	52.8	47.2	89.3	0.702	0.786	1.489
AVERAGE.....				596.2	269.7	326.5	428.7	45.2	54.8	121.0	0.762	0.629	1.391
2-3-1BOT	9.5	215.5	77.2	206.0	67.7	138.3	163.9	32.9	67.1	204.1	0.843	0.413	1.257
2-3-2TOP	9.5	251.5	129.2	242.0	119.7	122.3	167.6	49.5	50.5	102.1	0.729	0.714	1.444
AVERAGE.....				448.0	187.5	260.5	331.5	41.8	58.2	139.0	0.786	0.565	1.351
3-1-1BOT	9.5	212.1	75.3	202.6	65.8	136.9	161.8	32.5	67.5	208.1	0.846	0.406	1.253
3-1-2	9.5	220.4	86.1	210.9	76.6	134.3	163.3	36.3	63.7	175.4	0.822	0.469	1.291
3-1-3TOP	9.5	155.1	72.9	145.6	63.4	82.2	106.2	43.5	56.5	129.8	0.774	0.597	1.371
AVERAGE.....				559.1	205.7	353.4	431.3	36.8	63.2	171.8	0.819	0.477	1.296
3-2-1BOT	9.5	219.4	77.3	209.9	67.8	142.1	167.8	32.3	67.7	209.6	0.847	0.404	1.251
3-2-2	9.5	238.5	83.4	229.0	73.9	155.1	183.1	32.3	67.7	209.7	0.847	0.404	1.251
3-2-3TOP	9.5	229.7	93.9	220.2	84.4	135.8	167.7	38.3	61.7	160.8	0.809	0.503	1.313
AVERAGE.....				659.1	226.2	432.9	518.6	34.3	65.7	191.4	0.835	0.436	1.271
3-3-1BOT	9.5	222.8	74.9	213.3	65.4	147.9	172.7	30.7	69.3	226.2	0.857	0.379	1.235
3-3-2	9.5	222.1	79.7	212.6	69.2	143.4	169.6	32.5	67.5	207.2	0.845	0.408	1.253
3-3-3TOP	9.5	229.3	93.2	219.8	83.7	136.1	167.8	38.1	61.9	162.6	0.811	0.499	1.310

AVERAGE.....

645.7 218.3 427.4 510.1 33.8 66.2 195.8 0.839 0.428 1.266

NOTES.....

ALL CALCULATIONS ASSUME THAT SAMPLES ARE COMPLETELY SATURATED
CALCVOL = WATER VOL + (DRY WGT SOLIDS/SPECIFIC GRAVITY SOLIDS)
PORE = WATER LOSS/((WATER LOSS + (DRY WGT/SOLIDS S.G.))
DRYDEN = DRY WEIGHT/((WATER LOSS + (DRY WGT/SOLIDS S.G.))
BLKDEN = WET WEIGHT/((WATER LOSS + (DRY WGT/SOLIDS S.G.))

FILE NAME.. CORESMAR.11
DATE..... 03-12-1985

TABLE B29

VALLEY B. FIELD NO.

FILE NO. 1000170

KEY LAKE PROJECT
MONITORING OF LAYERED URANIUM TAILINGS TAIL
MOISTURE/DENSITY PROBE READINGS & CALCULATIONS

DATE OF READINGS.....10-17-84
MOISTURE STANDARD COUNT.....7000
DENSITY STANDARD COUNT.....6400

STATION...MD1-B

LEVEL	MOIST READ	DENSITY READ	DUMMY READ	DEN-DUM READ	MOIST RATIO	DENSITY RATIO	WATER (t/m ³)	BLK DEN (t/m ³)	DRY DEN (t/m ³)	M/D (%)	SOLIDS (%)	MOISTURE (%)
2.80	2054	29932	0	0	0.722	0.000	0.516	0.000	0.000	0.00	0.00	0.00
2.50	3042	46185	26011	20174	0.475	1.166	0.726	1.479	0.713	101.76	49.56	51.44
2.20	3255	47284	27047	20237	0.465	1.160	0.732	1.440	0.660	113.58	45.75	54.25
1.90	3594	32268	12426	19862	0.513	1.101	0.870	1.476	0.604	144.50	40.89	59.11
AVERAGES based on all available readings							0.724	1.452	0.709	99.47	51.14	48.86
AVERAGES based on complete scans only							0.793	1.452	0.659	120.44	45.76	54.24

STATION...MD2-B

LEVEL	MOIST READ	DENSITY READ	DUMMY READ	DEN-DUM READ	MOIST RATIO	DENSITY RATIO	WATER (t/m ³)	BLK DEN (t/m ³)	DRY DEN (t/m ³)	M/D (%)	SOLIDS (%)	MOISTURE (%)
2.80	2566	31774	0	19862	0.369	0.000	0.604	0.000	0.000	0.00	0.00	0.00
2.50	3135	41549	23315	18234	0.449	2.847	0.750	1.629	0.979	85.79	53.94	46.06
2.20	3420	43111	22240	20871	0.489	3.259	0.826	1.785	0.559	147.66	40.35	59.65
1.90	3654	31526	13327	18199	0.522	2.842	0.998	1.670	0.744	119.47	45.57	54.43
AVERAGES based on all available readings							0.767	1.549	0.782	98.19	50.46	49.54
AVERAGES based on complete scans only							0.822	1.549	0.727	113.00	46.95	53.05

STATION...MD3-B

LEVEL	MOIST READ	DENSITY READ	DUMMY READ	DEN-DUM READ	MOIST RATIO	DENSITY RATIO	WATER (t/m ³)	BLK DEN (t/m ³)	DRY DEN (t/m ³)	M/D (%)	SOLIDS (%)	MOISTURE (%)
2.80	2595	30917	0	18199	0.371	0.000	0.607	0.000	0.000	0.00	0.00	0.00
2.50	3148	48206	29727	18477	0.450	2.685	0.754	1.606	0.852	88.24	50.97	49.03
2.20	3726	52856	29759	23099	0.533	3.607	0.909	1.192	0.294	319.48	33.84	66.16
1.90	3637	40417	18611	21806	0.520	3.405	0.884	1.703	0.419	211.08	32.15	67.85
AVERAGES based on all available readings							0.789	1.367	0.579	136.13	42.75	57.25
AVERAGES based on complete scans only							0.949	1.367	0.518	163.69	37.92	62.08
OVERALL AVERAGES BASED ON ALL AVAILABLE READINGS							0.760	1.456	0.696	109.14	47.92	52.08
OVERALL AVERAGES BASED ON COMPLETE SCANS ONLY							0.821	1.456	0.625	129.37	43.60	56.40

CALIBRATION DATA USED:

$$\text{PORE MOISTURE} = (\text{MRATIO} \times 1.6 \times 10^{-3}) - 0.064$$

$$\text{BLK DENSITY} = (1 - \text{LN}(\text{DRATIO} + 2.35)) / (3.92) \times 31242 - 0.1$$

TABLE B30

FILE # 104. F. 10. 10. 10. 10. 10.

KEY LAKE PROJECT
MONITORING OF LAYERED URANIUM TAILINGS - PHASE 1
MOISTURE/DENSITY PROBE READINGS & CALCULATIONS

DATE OF READINGS.....11-22-84
MOISTURE STANDARD COUNT..... 7055.1
DENSITY STANDARD COUNT..... 6490.7

STATION...ND1-A

LEVEL	MOIST READ	DENSITY READ	DUMMY READ	DEN-DUM READ	MOIST RATIO	DENSITY RATIO	WATER (t/m3)	BLK DEN (t/m3)	DRY DEN (t/m3)	M/C (%)	SOLIDS (%)	MOISTURE (%)
1.50	3211	52964	35902	27062	0.455	4.169	0.764	0.904	0.140	546.20	12.47	54.57
2.20	3179	58576	34396	24180	0.445	3.725	0.745	1.129	0.384	193.74	34.04	55.76
2.00	3590	53484	29259	24225	0.509	3.732	0.864	1.126	0.262	330.09	23.25	76.75
1.70	3274	52050	29060	23990	0.464	3.696	0.781	1.145	0.364	214.24	31.82	68.18
1.40	3100	44278	27028	21210	0.439	3.268	0.735	1.330	0.645	113.81	48.77	50.22
AVERAGES based on all available readings							0.778	1.137	0.359	216.49	31.60	68.40
AVERAGES based on complete scans only							0.778	1.137	0.359	216.49	31.60	68.40

STATION...ND2-A

LEVEL	MOIST READ	DENSITY READ	DUMMY READ	DEN-DUM READ	MOIST RATIO	DENSITY RATIO	WATER (t/m3)	BLK DEN (t/m3)	DRY DEN (t/m3)	M/C (%)	SOLIDS (%)	MOISTURE (%)
1.50	3217	59409	37609	21800	0.470	3.359	0.792	1.329	0.537	147.52	40.40	59.60
2.20	3380	57378	35158	22220	0.479	3.423	0.809	1.293	0.494	167.02	37.45	62.55
2.00	3610	53176	29789	23387	0.512	3.603	0.869	1.194	0.325	267.20	27.22	72.77
1.70	3473	52358	29514	22844	0.492	3.519	0.933	1.240	0.407	204.76	32.81	67.19
1.40	2981	42904	21852	21054	0.423	3.244	0.703	1.394	0.691	101.82	49.55	50.45
AVERAGES based on all available readings							0.801	1.290	0.489	163.93	37.89	62.11
AVERAGES based on complete scans only							0.801	1.290	0.489	163.93	37.89	62.11

STATION...ND3-A

LEVEL	MOIST READ	DENSITY READ	DUMMY READ	DEN-DUM READ	MOIST RATIO	DENSITY RATIO	WATER (t/m3)	BLK DEN (t/m3)	DRY DEN (t/m3)	M/C (%)	SOLIDS (%)	MOISTURE (%)
1.50	3287	58958	37790	21178	0.467	3.263	0.787	1.382	0.596	171.93	43.12	56.88
2.20	3479	55194	33308	21877	0.493	3.370	0.835	1.322	0.438	171.19	36.86	63.14
2.00	3606	51799	29204	22594	0.511	3.481	0.868	1.261	0.393	221.17	31.14	68.86
1.70	3377	53445	31586	21859	0.479	3.369	0.808	1.324	0.516	156.82	38.73	61.27
1.40	3150	44454	27025	21419	0.446	3.300	0.748	1.362	0.614	121.76	45.09	54.91
AVERAGES based on all available readings							0.809	1.330	0.521	155.19	39.19	60.81
AVERAGES based on complete scans only							0.809	1.330	0.521	155.19	39.19	60.81
OVERALL AVERAGES BASED ON ALL AVAILABLE READINGS							0.796	1.252	0.456	174.39	36.44	63.56
OVERALL AVERAGES BASED ON COMPLETE SCANS ONLY							0.796	1.252	0.456	174.39	36.44	63.56

VALIDATION DATA USED:

PORE MOISTURE = (M/RATIO-1.863)/0.024
DUM DENSITY = (D-DUM)/(RATIO-1.351/2.92)/0.71241-0.1

TABLE B31

KEY LAKE PROJECT
MONITORING OF LAYERED URANIUM TAILINGS - PHASE 1
MOISTURE/DENSITY PROBE READINGS & CALCULATIONS

DATE OF READINGS.....01-02-83
MOISTURE STANDARD COUNT..... 7179
DENSITY STANDARD COUNT..... 7133

STATION...MD1-A

	MOIST	DENSITY	DUMMY	DEN-DUM	MOIST	DENSITY	WATER	BLK DEN	DRY DEN	M/C	SOLIDS	MOISTURE
LEVEL	READ	READ	READ	READ	RATIO	RATIO	(t/m ³)	(t/m ³)	(t/m ³)	(%)	(%)	(%)
2.80	3353	58241	34642	21599	0.467	3.029	0.941	1.407	0.566	143.69	40.21	59.79
2.50	2999	60700	42556	18142	0.418	2.543	0.738	1.618	0.681	83.75	54.42	45.58
2.20	3293	58182	37221	20961	0.459	2.939	0.824	1.444	0.620	132.95	42.93	57.07
2.00	3465	51869	30333	21486	0.483	3.012	0.874	1.414	0.540	162.04	38.16	61.84
1.70	3048	52057	30260	21797	0.425	3.056	0.752	1.396	0.644	116.80	46.17	53.83
1.40	2752	43291	17400	25891	0.382	2.630	0.666	1.188	0.522	127.45	43.97	56.03
AVERAGES based on all available readings							0.783	1.411	0.629	124.46	44.55	55.45
AVERAGES based on complete scans only							0.783	1.411	0.629	124.46	44.55	55.45

STATION...MD2-A

	MOIST	DENSITY	DUMMY	DEN-DUM	MOIST	DENSITY	WATER	BLK DEN	DRY DEN	M/C	SOLIDS	MOISTURE
LEVEL	READ	READ	READ	READ	RATIO	RATIO	(t/m ³)	(t/m ³)	(t/m ³)	(%)	(%)	(%)
2.80	3206	62627	39387	23440	0.447	3.286	0.799	1.308	0.510	156.59	38.97	61.03
2.50	2890	64147	43914	20233	0.403	2.837	0.706	1.486	0.780	90.48	52.50	47.50
2.20	3077	56994	36621	20373	0.429	2.856	0.761	1.478	0.717	106.05	48.53	51.47
2.00	3225	52197	30905	21382	0.449	2.993	0.804	1.420	0.516	130.62	43.36	56.64
1.70	2975	50764	29781	20982	0.414	2.742	0.721	1.442	0.711	102.74	49.32	50.68
AVERAGES based on all available readings							0.760	1.427	0.667	113.96	46.74	53.26
AVERAGES based on complete scans only							0.760	1.427	0.667	113.96	46.74	53.26

STATION...MD3-A

	MOIST	DENSITY	DUMMY	DEN-DUM	MOIST	DENSITY	WATER	BLK DEN	DRY DEN	M/C	SOLIDS	MOISTURE
LEVEL	READ	READ	READ	READ	RATIO	RATIO	(t/m ³)	(t/m ³)	(t/m ³)	(%)	(%)	(%)
2.80	3467	57983	36476	21512	0.483	3.016	0.875	1.412	0.537	162.76	38.06	61.94
2.50	3093	60099	42093	19006	0.431	2.524	0.765	1.629	0.862	88.79	52.97	47.03
2.20	3243	54623	33975	20648	0.452	2.895	0.809	1.462	0.653	124.02	44.64	55.36
2.00	3317	51740	30568	21172	0.462	2.968	0.831	1.432	0.601	138.35	41.96	58.04
1.70	2967	52065	31656	20409	0.413	2.861	0.729	1.476	0.747	97.49	50.64	49.36
AVERAGES based on all available readings							0.802	1.482	0.680	117.91	45.89	54.11
AVERAGES based on complete scans only							0.802	1.482	0.680	117.91	45.89	54.11
OVERALL AVERAGES BASED ON ALL AVAILABLE READINGS							0.782	1.438	0.657	119.01	45.66	54.34
OVERALL AVERAGES BASED ON COMPLETE SCANS ONLY							0.782	1.438	0.657	119.01	45.66	54.34

ALIBRATION DATA USED:

PORE MOISTURE = (MRATIO*2.0773)-0.139
BULK DENSITY = 2.748-1.21*LD5(DRATIO)

[illegible]

KEY LAKE PROJECT

DATE OF READINGS.....01-10-85
MOISTURE STANDARD COUNT..... 7178
DENSITY STANDARD COUNT..... 7133

	MOIST	DENSITY	DUMMY	DEN-DUM	MOIST	DENSITY	WATER	BLK DEN	DRY DEN	M/C	SOLIDS	MOISTURE
LEVEL	READ	READ	READ	READ	RATIO	RATIO	(t/m3)	(t/m3)	(t/m3)	(%)	(%)	(%)
1.80	2406	35907	15812	20095	0.335	2.817	0.565	1.495	0.930	60.69	62.23	77.77
2.50	3056	57519	31797	25721	0.426	3.506	0.755	1.196	0.441	170.95	76.91	67.09
2.20	2965	53705	26974	24731	0.413	3.467	0.728	1.244	0.516	141.21	41.46	58.54
AVERAGES based on all available readings							0.692	1.311	0.629	109.49	47.97	52.03
AVERAGES based on complete scans only							0.682	1.311	0.629	109.48	47.97	52.03

	MOIST	DENSITY	DUMMY	DEN-DUM	MOIST	DENSITY	WATER	BLK DEN	DRY DEN	M/D	SOLIDS	MOISTURE
LEVEL	READ	READ	READ	READ	RATIO	RATIO	(t/m ³)	(t/m ³)	(t/m ³)	(%)	(%)	(%)
2.50	2613	35827	17222	18605	0.364	2.608	0.625	1.588	0.963	54.92	60.64	59.36
2.50	2972	47514	25534	21979	0.414	3.081	0.730	1.386	0.856	111.24	47.34	52.66
2.26	3284	45323	23520	21803	0.456	3.057	0.821	1.396	0.575	142.90	41.17	58.83
2.00	3419	37906	12132	25774	0.476	3.613	0.960	1.194	0.333	259.33	27.91	72.09
AVERAGES based on all available readings							0.759	1.391	0.632	120.18	45.42	54.58
AVERAGES based on complete scans only							0.759	1.391	0.632	120.18	45.42	54.58

	MOIST	DENSITY	DUMMY	DEN-DUM	MOIST	DENSITY	WATER	BLK DEN	DRY DEN	M/C	SOLIDS	MOISTURE
LEVEL	READ	READ	READ	READ	RATIO	RATIO	(#/M3)	(#/M3)	(#/M3)	(%)	(%)	(%)
1.30	2679	34718	15702	19016	0.373	2.666	0.644	1.582	0.917	70.26	59.73	41.27
2.50	3125	54796	32477	22319	0.435	3.129	0.775	1.368	0.593	120.69	43.35	56.65
2.20	3659	59581	32741	24540	0.510	3.763	0.931	1.145	0.214	435.88	18.65	81.34
1.00	3542	43142	17968	25274	0.493	3.543	0.897	1.217	0.321	279.76	26.33	73.67
AVERAGES based on all available readings							0.812	1.323	0.511	158.94	38.63	61.37
AVERAGES based on complete scans only							0.812	1.323	0.511	158.94	38.63	61.37
OVERALL AVERAGES BASED ON ALL AVAILABLE READINGS							0.757	1.345	0.587	129.00	43.67	56.33
OVERALL AVERAGES BASED ON COMPLETE SCANS ONLY							0.757	1.345	0.587	129.00	43.67	56.33

```

PORE MOISTURE = (MRATIO*2.099)-0.139
BULK DENSITY = 2.748-1.21*LOG (DRATIO)

```


TABLE B33

REV. LAKE PROJECT
MONITORING OF LAYERED DEWATERING LINES - PHASE 1
MOISTURE DENSITY PROBE READINGS & CALCULATIONS

DATE OF READINGS.....02-11-88
MOISTURE STANDARD COUNT..... 7106.2
DENSITY STANDARD COUNT..... 7106.8

STATION...MD1-A

LEVEL	MOIST READ	DENSITY READ	DUMMY READ	DEN-DUM READ	MOIST RATIO	DENSITY RATIO	WATER (t/m ³)	BLK DEN (t/m ³)	DRY DEN (t/m ³)	W/C (%)	SOLIDS (%)	MOISTURE (%)
2.80	3139	61556	34398	27168	0.442	3.623	0.768	1.128	0.737	232.87	29.55	70.05
2.50	3808	60934	40025	20909	0.395	2.943	0.690	1.442	0.752	91.85	52.12	47.88
2.20	3148	57295	24101	22194	0.443	3.264	0.791	1.317	0.526	150.43	39.97	60.07
2.00	3233	51598	28570	23019	0.455	3.239	0.816	1.326	0.510	160.15	38.45	61.55
1.70	2795	50768	27471	23297	0.393	3.279	0.657	1.311	0.625	109.92	47.62	52.38
1.40	2823	42395	16507	26398	0.397	3.714	0.695	1.150	0.486	149.24	40.12	59.88
AVERAGES based on all available readings							0.744	1.280	0.576	138.96	41.65	58.35
AVERAGES based on complete scans only							0.744	1.280	0.536	138.96	41.65	58.35

STATION...MD2-A

LEVEL	MOIST READ	DENSITY READ	DUMMY READ	DEN-DUM READ	MOIST RATIO	DENSITY RATIO	WATER (t/m ³)	BLK DEN (t/m ³)	DRY DEN (t/m ³)	W/C (%)	SOLIDS (%)	MOISTURE (%)
2.80	3307	59265	0	26398	0.465	0.000	0.838	0.000	0.000	0.00	0.00	0.00
2.50	3009	60590	0	26398	0.423	0.000	0.750	0.000	0.000	0.00	0.00	0.00
2.20	3063	55329	0	26398	0.431	0.000	0.766	0.000	0.000	0.00	0.00	0.00
2.00	3282	51640	0	26398	0.462	0.000	0.870	0.000	0.000	0.00	0.00	0.00
1.70	2917	48847	27753	21094	0.410	2.969	0.723	1.431	0.709	101.95	49.52	50.48
1.40	2637	40791	14596	26205	0.371	3.688	0.640	1.169	0.529	120.97	45.25	54.75
AVERAGES based on all available readings							0.759	1.300	0.542	139.69	41.72	58.28
AVERAGES based on complete scans only							0.681	1.300	0.619	110.09	47.60	52.40

STATION...MD3-A

LEVEL	MOIST READ	DENSITY READ	DUMMY READ	DEN-DUM READ	MOIST RATIO	DENSITY RATIO	WATER (t/m ³)	BLK DEN (t/m ³)	DRY DEN (t/m ³)	W/C (%)	SOLIDS (%)	MOISTURE (%)
2.80	3228	59012	37134	21678	0.454	3.079	0.914	1.337	0.573	142.20	41.29	58.71
2.50	2844	53994	40333	18661	0.400	2.626	0.701	1.590	0.379	79.79	55.62	44.38
2.20	3192	53789	33013	20776	0.449	2.924	0.804	1.450	0.346	124.45	44.55	55.45
2.00	3279	51479	30277	21202	0.461	2.984	0.570	1.425	0.596	137.26	41.80	58.20
1.70	2909	50873	29307	21570	0.409	3.036	0.720	1.404	0.634	105.28	43.71	56.29
1.40	2514	46688	16950	29838	0.354	4.199	0.604	1.012	0.408	147.56	40.34	59.66
AVERAGES based on all available readings							0.745	1.376	0.631	119.16	45.84	54.16
AVERAGES based on complete scans only							0.745	1.376	0.631	119.16	45.84	54.16
OVERALL AVERAGES BASED ON ALL AVAILABLE READINGS							0.749	1.324	0.575	130.29	43.42	56.58
OVERALL AVERAGES BASED ON COMPLETE SCANS ONLY							0.776	1.324	0.388	125.06	44.43	55.57

CALIBRATION DATA USED:

PORE MOISTURE = CMRATIO*21.0992+0.1377

TABLE B34

FIELD NO. 100

KEY LINE PROJECT
 MONITORING OF COVERED URANIUM TAILINGS PHASE I
 MOISTURE DENSITY FIELD READINGS - CALCULATIONS

DATE OF READINGS.....02-10-85
 MOISTURE STANDARD COUNT..... 7106.2
 DENSITY STANDARD COUNT..... 0

STATION...MD1-B

	MOIST	DENSITY	DUMMY	DEN-DUM	MOIST	DENSITY	WATER	BLK DEN	DRY DEN	M/C	SOLIDS	MOISTURE
LEVEL	READ	READ	READ	READ	RATIO	RATIO	(t/m ³)	(t/m ³)	(t/m ³)	(%)	(%)	(%)
1.10	3793	0	0	0	0.534	0.000	0.981	0.000	0.000	0.00	0.00	0.00
AVERAGES based on all available readings							0.981	0.000	0.000	0.00	0.00	0.00

STATION...MD2-B

	MOIST	DENSITY	DUMMY	DEN-DUM	MOIST	DENSITY	WATER	BLK DEN	DRY DEN	M/C	SOLIDS	MOISTURE
LEVEL	READ	READ	READ	READ	RATIO	RATIO	(t/m ³)	(t/m ³)	(t/m ³)	(%)	(%)	(%)
1.20	3819	0	0	0	0.537	0.000	0.985	0.000	0.000	0.00	0.00	0.00
AVERAGES based on all available readings							0.985	0.000	0.000	0.00	0.00	0.00

STATION...MD3-B

	MOIST	DENSITY	DUMMY	DEN-DUM	MOIST	DENSITY	WATER	BLK DEN	DRY DEN	M/C	SOLIDS	MOISTURE
LEVEL	READ	READ	READ	READ	RATIO	RATIO	(t/m ³)	(t/m ³)	(t/m ³)	(%)	(%)	(%)
1.05	4072	0	0	0	0.573	0.000	1.064	0.000	0.000	0.00	0.00	0.00
AVERAGES based on all available readings							1.011	0.000	0.000	0.00	0.00	0.00
OVERALL AVERAGES BASED ON ALL AVAILABLE READINGS							1.011	0.000	0.000	0.00	0.00	0.00

CALIBRATION DATA USED:

WET MOISTURE = $\ln(RATIO) \times 2.0792 - 0.179$
 BULK DENSITY = $2.748 - 1.21 \times \ln(RATIO)$

KEY LANE PROJECT
MONITORING OF LAYERED URANIUM TAILINGS - PHASE 1
MOISTURE-DENSITY CORRE READINGS & CALCULATIONS

DATE OF READINGS.....07-08-85
MOISTURE STANDARD COUNT..... 7322.7
DENSITY STANDARD COUNT..... 7151

STATION...MD3-A

LEVEL	MOIST READ	DENSITY READ	DUMMY READ	DEN-DUM READ	MOIST RATIO	DENSITY RATIO	WATER (t/m ³)	BLK DEN (t/m ³)	DRY DEN (t/m ³)	H/C (%)	SOLIDS (%)	MOISTURE (%)
2.80	3745	59704	37530	22174	0.457	3.100	0.922	1.379	0.559	145.54	40.55	39.44
2.50	2205	58446	39328	19038	0.393	2.664	0.665	1.562	0.998	74.08	57.44	42.56
2.20	3233	54007	32505	21522	0.441	3.005	0.787	1.415	0.630	124.98	44.45	35.55
2.00	3516	51437	29514	21827	0.453	3.009	0.812	1.415	0.604	124.82	42.65	37.35
1.80	2951	49195	27439	21756	0.403	3.041	0.757	1.402	0.695	101.65	49.59	30.41
1.40	2675	46776	15887	30889	0.365	4.318	0.628	0.979	0.350	179.14	75.82	54.18
1.10	1612	37222	6128	31094	0.220	4.346	0.323	0.970	0.547	49.90	65.71	34.29
AVERAGES based on all available readings							0.677	1.303	0.626	108.15	43.04	31.96
AVERAGES based on complete scans only							0.677	1.303	0.626	108.15	43.04	31.96
OVERALL AVERAGES BASED ON ALL AVAILABLE READINGS							0.677	1.303	0.626	108.15	43.04	31.96
OVERALL AVERAGES BASED ON COMPLETE SCANS ONLY							0.677	1.303	0.626	108.15	43.04	31.96

CALIBRATION DATA USED:

PORE MOISTURE = (DRATIO*2.099)-0.139
BULK DENSITY = 2.748-1.21*LOG(DRATIO)

TABLE B36

MONITORING OF LAYERED URANIUM TAILINGS - PHASE I

MOISTURE DENSITY PROBE READINGS

DATE: OCT 19, 1984 CALIBRATION: BURNS, OPERATOR: JPH/HB

TUBE NO.	DEPTH	MOISTURE (ST. COUNTS = 6000)			DENSITY (ST. COUNTS = 7000)				BULK DENSITY (t/m ³)	REMARKS
		READING	RATIO	MOISTURE (t/m ³)	PROBE READING	DENSITY READING	DIFFERENCE	RATIO		
WET DEPT	Bottom	2557			52 852	51653	"			"2 min. reading"
		2646			52628					
		2601.5	0.371		52 788	52920	1867	3.102		
+ 100		2729			52 230	52007	"			
		2703			52 257					
		2716	0.365		52 105	53101	15705	2.999		Measured $\gamma = 1.531 \text{ t/m}^3$
		(av) 0.379					(av) 3.051			Measured $\rho_w = 0.607 \text{ t/m}^3$
DRY DEPT	Bottom	2286			25445	27556	"			
		2395			26075					
		2290	0.327		25871.5	28409	16 537.5	2.580		
+ 100		2111			26221	25787	"			
		2166			25805					
		2188.5	0.305		25863	29196	16 666	2.602		Measured $\gamma = 1.762 \text{ t/m}^3$
		(av) 0.316					(av) 2.591			Measured $\rho_w = 0.466 \text{ t/m}^3$

MONITORING OF LAYERED URANIUM TAILINGS - PHASE I

MOISTURE DENSITY PROBE READINGS

DATE: OCT 17, 1984 SITE: B OPERATOR: JPH/HB

TUBE NO.	DEPTH	MOISTURE (ST. COUNTS = 6000)			DENSITY (ST. COUNTS = 7000)				BULK DENSITY (t/m ³)	REMARKS
		READING	RATIO	MOISTURE (t/m ³)	PROBE READING	DENSITY READING	DIFFERENCE	RATIO		
M01-B	Bottom	3280			28 832					"Av. of two readings"
	+ 100	3042			46 285					+ Reading taken
	+ 600	3265			47230					
	+ 900	3590			52288					
		(av) 3046	0.433							
M02-B	Bottom	2586			31 721.5					
	+ 100	3165			41 505					
	+ 600	3070			42 111					
	+ 900	3650			31526					
		(av) 3198	0.457							
M03-B	Bottom	2795			30517					
	+ 100	3108			48 206					
	+ 600	3728			37855					
	+ 900	3637			40007					
		(av) 3277	0.468							Measured core: $\gamma = 1.382 \text{ t/m}^3$
		(av) 0.432								Measured core: $\rho_w = 0.766 \text{ t/m}^3$

TABLE B37

KEY LAKE PROJECT
MONITORING OF LAYERED URANIUM TAILINGS - PHASE I
SUMMARY OF RADON EXHALATION DATA COLLECTED

B37(A) Fall Sampling Period				B37(C) Deep Winter Sampling Period			
Date	Site	Time Interval (minutes)	Radon Concentration pCi/L	Date	Site	Time Interval (minutes)	Radon Concentration pCi/L
			Unit 11 Unit 26 Unit 28				Unit 11 Unit 26 Unit 28
13/09/84	1	0-15	42	13/02/84	A	0-17	606
		15-30	111			17-25	354
		30-45	128			75-136	157
13/09/84	1	0-45	306			136-189	84
		45-60	692			189-290	69
		65-119	354			189-290	69
13/08/84	2	119-178	516			290-384	74
		0-15	99	14/02/85	B	384-470	99
		15-30	275			0-17	3394
		30-45	169			17-45	1728
14/09/84	3	45-60	286			85-63	349
		60-120	9			163-223	67
		120-285	8	14/02/85	A	223-303	32
		285-480	10		(on snow)	0-16	17
		480-630	7			16-81	24
15/09/84	4	0-120	450			81-148	19
		120-240	1645	14/02/85	A	148-202	21
		240-420	3096		(on snow)	0-29	24
		420-530	4194			16-18	19
						81-148	13
						148-202	21
						0-29	21
						29-39	18
						59-124	32
						124-175	43
B37(B) Early Winter Sampling Period				* Outdoor temperature during this sampling period average -25°C			
Date	Site	Time Interval (minutes)	Radon Concentration pCi/L	B37(D) Late Winter Sampling Period			
			Unit 11 Unit 26 Unit 28				
20/11/84	A	0-17	6	8/03/85	6	0-28	3355
		17-139	8			28-44	2611
		139-263	5			44-65	1220
		263-389	12			65-105	1127
		389-1341	27			105-158	475
22/11/84	A	1341-1595	47			158-200	314
		0-22	16			200-235	240
		22-44	70			0-19	3240
		44-67	94		A	19-43	2285
		67-101	111			43-61	1876
		101-116	158			61-135	820
		116-367	299			135-226	354
		367-448	419			226-284	264
		448-1286	526			284-368	201
						368-452	160
						0-16	2906
					B	16-28	2266
						28-44	1385
						44-139	513
						139-206	227
						206-262	147

* Outdoor temperature during this sampling period average -25°C

TABLE B38

MONITORING OF LAYERED URANIUM TAILINGS - PHASE I

RADON MEASUREMENTS BY TRAK-ETCH TECHNIQUE

<u>Unit No.</u>	<u>Location/Description</u>	<u>Duration of Exposure (hrs)</u>	<u>Radon Concentration pCi/L</u>
46	Site A - frozen tails	66	90.4
48	Site A - surface of snow	672	155.36
49	Site B - frozen surface (ice/tails)	648	123.31
50	Monitoring hut - on wall	600	9833.39
61	Site B - frozen surface (ice/tails)	90	807.20
64	Site A - frozen tails	90	142068.56
65	Site A - frozen tails	672	29574.62

APPENDIX C

**EXCERPTS FROM TESTWORK CARRIED OUT
BY
SASKATCHEWAN RESEARCH COUNCIL**

- (i) LETTER RE TAILINGS OBSERVATIONS**
- (ii) NOTES ON TEST PROCEDURES FOR LEACHATE
STUDY**
- (iii) MINERALOGY REPORT**



Saskatchewan
Research Council

KNIGHT & PIESOLD LTD		1985	
RECEIVED	FILE		
Name	PK	PH	HD
Routing	/		
Date Recd	VFA		
Action By			
Reply To			

30 Campus Drive Saskatoon, Sask. Canada S7N 0X4 Phone: (306) 664-5400 Telex: SARECO 074-2484

February 19, 1985

Knight and Piesold Limited
1350 United Kingdom Building
409 Granville Street
Vancouver, B.C.
V6C 1T2

Attention: J.P. Haile, P.Eng.

Dear Sir:

There have been a number of observations and recollections made concerning the tailings which I have been working with that may be of some interest to you.

The samples were received in a triple plastic bag. Preliminary investigations found three distinctive layers of solids and a small amount of free liquid. The largest portion of solids was comprised of a dark grey sandy material, the middle section appeared to be a reddish brown mud, and the smallest fraction was a thin light tan slime. There were some problems encountered in getting a representative sample, the free liquid would not mix back into the solids and the slimes and excess free liquid adhered in small globules to the plastic bag, which were not easily scraped off. The solids, upon mixing, I recall took on the colour of the reddish brown mud.

The initial pore water extraction yielded an interesting observation as well. After the pore water was removed the solids appeared somewhat darker, but basically reddish brown. The samples once dried however were a light cream-grey and unexpectedly light, moisture content was found to be plus 60%.

The first wash of sample A3 yielded more liquid returned than expected. The 3 to 1 wash required 1096 g of water to be added, when 1161.84 g was collected. The discrepancy was noted with interest. The explanation put forth was that the 24 hours of mixing created a more homogenous sample, therefore less channeling in the pressure filter, yielding more water.

There are four other points which are perhaps of some interest to you. The first being that during the filtration of the 5 to 1 wash, clear liquid was noted above the unfiltered material. This would indicate a very short settling period due to flocculation or perhaps a coarse material. It should also be noted that the filter cakes from the pressure filter did not disperse easily in water. The cakes had to be broken apart and vigorously stirred before they would go into suspension. A third point is, the material received was a thick paste, the 3 to 1 was lower in viscosity but still a thin gelatin-like soup, where 5 to 1 was very fluid. The final point is that during the 3 micron filtration there was some froth developed at the discharge of the filter.

There may well be other phenomenon which have occurred but not observed or noted. I hope that the observations which were made are of some value to you in your investigation. If you have any questions or if I can be of further assistance please contact me.

Yours truly,



Roy McKnight
Research Technician
Resources Sector

RM/bg

P.S. Please find enclosed water sample analysis.



Saskatchewan
Research Council

Re: Knight and Piesold Contract

D.S.S. File 265-Q-23241-4-1679

SRC Project R-836-3

The September and October water samples determination of Eh and pH are not included in the notes. It may be of interest however to know that the measurements were done using a Fisher Accumet model 620 meter. The standard reference solution was a pH 4 buffer, saturated with quinhydrone. The other sample analyses of liquids and solids were carried out at the SRC Analytical laboratory. There are two exceptions, the analysis for Ion Exchange Cation Capacity was done by the University of Saskatchewan's soil testing laboratory, and the mineralogy was completed by the SRC geology sector.

There were a number of changes and complications in the analyses and procedures as the project progressed. The instructions followed were a modified version of procedure outlined in a letter dated September 6 1984. This described a seven step method, with the analyses requested and their priority. There was a flow sheet attached outlining the work.

The first sample processed was sample A3. This involved pressure filtering followed by three 24 hour leaches with pressure filtering after each. Samples A8, B1, B2 and B3 were then processed. These samples required only a brief wash and filtering. The final sample was A7, which was processed exactly the same as sample A3. This briefly describes the sequence in which the samples were completed.

The first reference concerning the leach testing is; the samples were received on November 26, 1984. They were tested for radioactivity

and found to be emitting 2 to 3 MR/h. The cardboard box received contained six plastic bags, labelled A3, A7, A8, B1, B2, B3. Their weight ranged from 3.5 to 4 kg each.

The plastic bag labelled A3 was opened, it was discovered to be actually triple bagged. This was a good thing as the middle bag held 50 plus mls of free water. The inner bag held the sample, which appeared to be a stiff sludge. The sludge appeared to have three distinctive parts. The largest was granular with a dark grey colour. The second fraction was a reddish brown mud-like layer and the third a light tan soupy slime. The bag was scraped as clean as possible and the free water returned to the sample.

An attempt was made to mix in the excess free water and obtain a representative sample for moisture determination. The mixture took on the colour of the reddish mud, and it should be noted that free water was contained but it is suspected not recombined. The other samples were treated in the same fashion and exhibited the same characteristics. The results of the moisture determinations are as follows:

A3	A7	A8	B1	B2	B3
61.69%	69.85%	68.57%	65.47%	72.79%	56.27%

The results should be viewed with suspicion, as it was difficult to recombine the free water for a representative sample. The results show much more variability than would be suspected by observation. The higher values of moisture content are considered to be the most accurate. Counting losses and samples there was only a kilo or less of dry material per sample; the initial sample weight would indicate a minimum of 75% water. Also, there was almost a litre of water extracted from

the sample and the water content of the filter cake was only slightly below that determined for the as-received sample. It was also observed that the oven dried samples were light grey in colour and remarkably light in weight.

Sample A3 was pressure filtered. There was about a litre of water extracted and the cake retained 60.59% moisture. The first leach was started. This wash required three parts distilled water to one part dry solids. It was decided a Winkworth Z blade mixer was needed, as the mixture was anticipated to be paste like. The amount of water added was not expected to drastically change the original physical characteristics. The mixing chamber required the sample to be split into three lots of 634.5 g wet solids and 365 g of water, each lot was mixed for 24 hours. The resulting slurry was not nearly as viscous as expected, it was more like a thick milkshake than a paste.

The amount of water recovered from the pressure filter was also unexpected. A total of 1161.84 g was recovered from the addition of 1096 g. The excess was gained from the water retained in the solid, presumably due to the improved filtration of the more homogeneous mixture reducing air channelling in the pressure filter. The filter cake obtained after the first leach contained only 46.97% moisture. As priorities changed the remaining 422.89 g of the material was leached to provide extra liquid for analysis.

The second leach, 5:1 ratio of sample A3 and water, was carried out in a 15 litre stainless steel tapered bucket. A Buffalo drill press, turning a 3 inch propellor at 960 rpm was used for the 24 hour mix. The pail was covered as completely as possible to minimize evaporation.

This arrangement was also used for all future leaches, including A7 first wash. It was suggested that a nitrogen or similar purge be added to prevent a reaction with oxygen that may alter the analysis, if a similar test is carried out in the future.

The second leach material was then pressure filtered. The third leach, again at 5:1 ratio followed. The samples requiring only the brief wash were then processed (A8, B1, B2, B3). The brief wash required slightly different handling. To accomplish the wash sufficient water was added to make up a 3:1 water to solids ratio. This slurry was mixed for 15 minutes before pressure filtering. Sample A7 used the identical method to A3, except for the mixing with the Winkworth blender.

The pressure filter used in the test was a BAROID drilling mud filter. The unit was operated at 30 psig controlled by an air regulator. The unit is relatively small with approximately 200 ml capacity and a filtering area of 45 square cm. The small size required many changes to complete the filtration of a single leach. Each load took 15 to 20 minutes, plus turnaround time. The liquid was drained out of the filter directly into one litre plastic sample bottles. The end point of filtration was indicated by the drop in pressure of a gauge mounted on the regulator.

Some points of possible interest follow. During the filtration of the 5:1 leaches of A3 and A7 clear water would appear on the top of the sample. It should also be noted that the filter cakes were all 45 to 50% moisture. The cakes themselves after filtering resembled pucks 8 cm in diameter and 20 mm high. The moisture content samples were thin

wedges taken out of several pucks. The pucks had to be broken apart with a spatula to be redispersed.

The liquid from the filters was intended to be measured for volume and weight. This step was unfortunately omitted in the haste of preparing the samples for analysis. The preparation involved vacuum filtering using a 3 cm Milli-pore vacuum filter with Nucle-pore 3.0 micron Membra-fill filters. This unit was operated at approximately 24 inches of mercury vacuum. It was observed that there was a small amount of white froth at the discharge of the filter while under full vacuum.

The samples were then split into the required quantities for analysis. One ml per litre of nitric acid was used for acidification when required. The samples for the radio nuclides (Ra 266 Th 228, 230, 232) had to be diluted to 2 litres. The dilution will effect the accuracy of the detection limits for these analyses. The amount of dilution is as follows:

	A3	A7	A8	B1	B2	B3
Pore Water	85%	87.5%	63%	50%	55%	50%
1st Wash	60%	50 %				

It should also be noted that the solids samples were taken after leaching, sample A3 and A7 after the third wash and the others after the brief wash. The samples submitted for mineralogical testing were of unleached material.

There was very little if any of the liquids remaining after analysis. There was as well less than a kilogram of dry solids remaining, the amount of sample A8 is unknown as it was required for the completion

of the consolidation test being carried out by the University Civil Engineering Department. The dregs of the liquid samples will be treated at the SRC pilot plant before disposal. The solid and other contaminated material from clean up and the material from the consolidation test will be sent back to Key Lake Mine for disposal.

MINERALOGY OF KEY LAKE TAILINGS

SAMPLES A3 AND A7

by

R.G. Arnold

for

Knight and Piesold Limited
Consulting Engineers
1350 United Kingdom Way
409 Granville Street
Vancouver, British Columbia
V6C 1T2

February, 1985

SRC Publication No. R-860-1-C-85

TABLE OF CONTENTS

	<u>Page</u>
MINERALOGY OF KEY LAKE TAILINGS SAMPLES A3 AND A7	1
Condition of Samples	1
Pre-treatment of Samples	1
Mineral Identification Techniques	1
Minerals Identified	2
Heavy Minerals	4
Qualitative Mineralogy of the Plus 5 Micron and the Minus 5 Micron Fractions	5
General Discussion	6

LIST OF TABLES

<u>Table</u>		<u>Page</u>
1	Quantitative Mineralogy of Bulk Samples	8
2	Chemical Analysis of Heavy Mineral Fractions	9

LIST OF FIGURES

<u>Figure</u>		<u>Page</u>
1.	Photomicrograph showing gypsum laths and round pisoliths in air. The largest pisolith shown is approximately 120 microns in diameter and the longest lath is 320 microns long by 40 microns wide.	10
1b.	Photomicrograph showing pisoliths in immersion oil. Largest pisolith (lower right) is 660 microns across. Some pisoliths show internal zoning and a thin outer rim.	

MINERALOGY OF KEY LAKE TAILINGS SAMPLES A3 AND A7

Condition of Samples

Samples A3 and A7 were as received from the pressure filtration treatment. Each sample was damp and compacted as if partially cemented together.

Pre-treatment of Samples

The samples were disaggregated for mineralogical analysis, by washing them in distilled water. Evaporation of the wash water at room temperature for several hours resulted in the formation of small, white laths and needles which were identified by X-ray diffraction analysis as gypsum. This suggests that the samples are rich in soluble calcium sulphate.

The minus 5 micron fraction of the samples was separated for mineral analysis by dispersing each sample in distilled water with calgon (sodium metaphosphate) or acetone, agitating with an ultrasonic probe, centrifuging for an appropriate time and then drawing off the suspended slurry for mineral analysis.

Heavy minerals were separated from the samples using a Haultain superpanner followed by a methylene iodide ($d_{20} = 3.325$) heavy liquid separation.

Mineral Identification Techniques

The minerals were identified by a combination of X-ray diffraction and microscopic methods. Several polished sections were made of heavy mineral separates for microscopic examination and electron probe analysis.

The X-ray methods employed were the smear-slide and powder camera techniques. In the smear-slide technique, a few milligrams of sample is

smearred onto a glass slide which is X-rayed, and a chart record of the diffraction lines is produced. In this technique, the sample is generally a mixture of minerals. In the powder camera technique, individual mineral grains are picked up with a fine glass fibre under high magnification, and the mineral is then X-rayed on the end of the fibre in a powder camera. The diffraction lines are recorded on 35 mm film.

Qualitative electron microprobe analyses were performed on a Cameca instrument at the Department of Geological Sciences, University of Saskatchewan.

Autoradiographs were taken of polished sections of heavy minerals and of individual grains glued to glass slides, by placing the mineral grains directly in contact with 35 mm X-ray diffraction film in a light-proof box. It is assumed that the film recorded alpha, beta and gamma activity.

Table 1 summarizes some quantitative mineralogical work on bulk samples, and Table 2 summarizes the chemical analysis of heavy mineral fractions separated from the bulk samples.

Minerals Identified

Samples A3 and A7 were identical mineralogically, consequently, the following descriptive details apply equally to both samples. All minerals were positively identified by X-ray diffraction unless indicated otherwise. Ideal chemical formulas were used for each mineral.

Quartz (SiO_2)

Quartz is the most abundant constituent and occurs as white, glassy, transparent to translucent grains.

Quartz also forms the thin outer shell of gypsum filled pisoliths or

spheres (see Figure 1). This was determined from powder camera patterns of the shell material after dissolving away the contents of pisoliths in water. The color of the quartz shells varies from white to dark brown. A few black pisoliths were observed.

Gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$)

Gypsum is a common constituent of the samples and occurs in the form of white, transparent needles or laths, as white opaque irregular shaped grains with a pebbly surface, and as the filling in pisoliths (see Figure 1). The pisoliths generally range between 60 to 180 microns in diameter. The laths are up to 560 microns in length and between 30 and 60 microns in width.

Graphite (C)

Graphite is relatively abundant and occurs as micaceous flakes.

Ettringite ($\text{Ca}_6\text{Al}_2(\text{SO}_4)_3(\text{OH})_{12} \cdot 26\text{H}_2\text{O}$)

Ettringite was identified in X-ray diffractions charts from the minus 5 micron fraction. Examination of the minus 5 micron fraction under the microscope suggested that ettringite consists of light green-brown translucent polycrystalline masses or clumps composed of numerous small sub-grains, which are only visible between crossed polarizers.

Bassanite ($2\text{CaSO}_4 \cdot \text{H}_2\text{O}$)

Bassanite was identified in some powder diffraction charts. It is possible that bassanite formed during sample or X-ray slide preparation and was not in the pressure filtered samples.

Clay Minerals

Illite (K, Al, Mg, Si, Ti, O, OH) and trichlorite (Al, Mg, Si, O, OH) were identified in the minus 5 micron fraction (see Table 1).

Amorphous Material

Diffraction charts of finer grained material separated from the bulk samples by simple slurry separation, showed quite prominent, broad "humps" between about 15 and 38 degrees two theta using CuK-alpha radiation. These broad "humps" are normally attributed to the presence of amorphous material.

Heavy Minerals

The following minerals were identified in heavy mineral separates.

Gersdorffite (NiAsS)

This is the most abundant heavy mineral. It occurs as dark, metallic, steel grey grains that show some evidence of chemical corrosion. None of the grains occurred as fresh fragments as one would expect from a freshly crushed ore. Cobalt was detected in gersdorffite by electron microprobe.

Millerite (NiS)

This is the second most abundant heavy mineral. It occurs as brass coloured needles and grains with a fibrous habit, and as individual well formed crystals. Cobalt was detected in millerite by electron microprobe.

Sphalerite (ZnFeS), chalcopyrite (CuFeS_2), pyrite (FeS_2)

Sphalerite, chalcopyrite and pyrite occur separately or together in composite grains. Cobalt was detected in pyrite by electron microprobe. Sphalerite and chalcopyrite were identified in polished sections only.

Hematite (Fe_2O_3)

Hematite is relatively abundant and occurs in two forms: as small reddish coloured grains with a lumpy or botryoidal texture and as small steel black cleavage flakes that show reddish internal reflections between crossed polarizers.

Geothite (HFeO_2)

Small brownish irregular shaped grains and clumps that show brown internal reflections between crossed polarizers.

Bravoite ($[\text{Ni}, \text{Fe}]\text{S}_2$)

Occurs as concentrically zoned grains that form composite grains with millerite and/or gersdorffite. Identified in polished sections and confirmed by electron microprobe.

Linnaeite (Co_3S_4)

Identified in polished sections and confirmed by electron microprobe analysis.

Covelite (CuS)

Small grains showing blue reflectivity in polished sections. Identified in polished sections only.

Galena (PbS)

Small, soft steel grey grains with cubic cleavage identified only in polished sections.

Rutile (TiO_2)

Skeletal grains pseudomorphous after ilmenite. Identified only in polished sections.

Qualitative Mineralogy of the Plus 5 Micron and the Minus 5 Micron Fractions.

Bulk samples were dispersed in distilled water with calgon and centrifuged. The yield of minus 5 micron fraction was 19.0 wt % for sample A3 and 17.5 wt % for sample A7.

Sample A3:

The minus 5 micron fraction contained trichlorite, illite, quartz with minor amounts of bassanite and amorphous material.

The plus 5 micron fraction contained abundant quartz with some trichlorite, illite and minor bassanite and amorphous material.

Sample A7:

The minus 5 micron fraction contained, quartz, trichlorite, illite, abundant ettringite and a trace of bassanite.

The plus 5 micron fraction contained abundant gypsum, some quartz, minor ettringite and traces of trichlorite, illite and amorphous material.

The inconsistencies in the occurrence of the various calcium sulphate hydrates is unexplained.

General Discussion

The mineralogy of the two samples can be divided into two groups: minerals that occur in the ore and pass through the milling process, and new minerals that probably formed during ore processing or after deposition of the tailings. The majority of the minerals belong to the first group, however, the calcium sulphate minerals, gypsum, ettringite and bassanite belong to the second group.

The chemical analyses of the heavy mineral fraction (Table 2), when interpreted in terms of the mineralogical results, suggest that the major constituents of the heavy mineral fraction are nickel, iron, cobalt arsenides, sulfides or sulfarsenides and iron oxides. Iron, zinc, copper and lead sulfides occur in minor quantities.

Electron microprobe analysis of 20 grains selected at random in a polished section confirmed the mineralogy identified by X-ray and microscopic work. No new minerals were identified. Probe work indicated that minerals rich in nickel generally contained some cobalt and vice versa.

The presence of 0.3 and 0.4% uranium in the heavy mineral fraction (Table 2) might suggest the presence of uranium minerals, but none were identified. A simple test was performed in an attempt to determine if uranium was adsorbed on the surfaces of other grains or occurred as uranium minerals that were not identified. Uranium was leached from a heavy mineral sample in 1N HNO₃ for 10 minutes at 60°C and at 90°C: the uranium in solution was 500 and 3200 ppm, respectively. The results indicated that uranium is readily stripped with a very weak acid solution, which suggests that it may be adsorbed on other minerals or occurs in some other readily available form.

Autoradiographs of the polished sections of heavy minerals indicated that many of the heavy minerals are radioactive. As the heavy mineral fraction is made up of normally non-radioactive sulfides, arsenides and some silicate impurities, a possible explanation again is that some of the radioactive elements are adsorbed on the surface of mineral grains. In one case autoradiographic work indicated that goethite (iron oxide hydrate) was radioactive.

Using a gamma ray detector it was found that the total sample, the heavy minerals, and a concentrate of quartz-gypsum pisoliths were weakly but measurably radioactive.

There was no evidence from X-ray powder camera films to suggest that amorphous material existed in the samples, as all mineral grains mounted on fibres produced powder patterns. However, the prominent, broad diffraction "humps" evident on some diffraction charts of finer grained material indicates the presence of amorphous material which may play a role in the adsorption of radioactive elements.

Table 1
Quantitative Mineralogy of Bulk Samples

Mineral concentrations of the most abundant minerals in the bulk samples, using acetone to prepare the smear slides were determined by X-ray diffraction techniques. The concentrations are in weight %.

<u>Mineral</u>	<u>Sample A3</u>	<u>Sample A7</u>
Quartz	53	77
Gypsum	24	16
Ettringite	8	2
Illite	7	3
Trichlorite	<u>8</u>	<u>2</u>
	100	100

Table 2

Chemical Analysis of Heavy Mineral Fractions

Two heavy mineral fractions were chemically analyzed to obtain an approximate estimate of the concentration of the metallic minerals. The yield of heavy minerals from the bulk samples varied between 0.3 to 0.6 weight %.

<u>Metals</u>	Sample A3 Wt %	Sample A7 Wt %
Ni	13.5	14.8
As	11.8	13.7
S	10.6	12.3
Fe ₂ O ₃	5.7	6.3
Zn	1.5	2.1
Pb	1.1	1.1
Co	0.9	0.9
Cu	0.4	0.4
U	0.3	0.4
	PPM	PPM
P ₂ O ₅	500	500
V	281	229
TiO ₂	100	100
Zr	86	122
Mn	60	70
Cd	52	95
Th	48	80
Mo	36	39
Y	33	45
Ba	18	16
Cr	17	12
La	13	16
Sr	6	17
Be	2	2

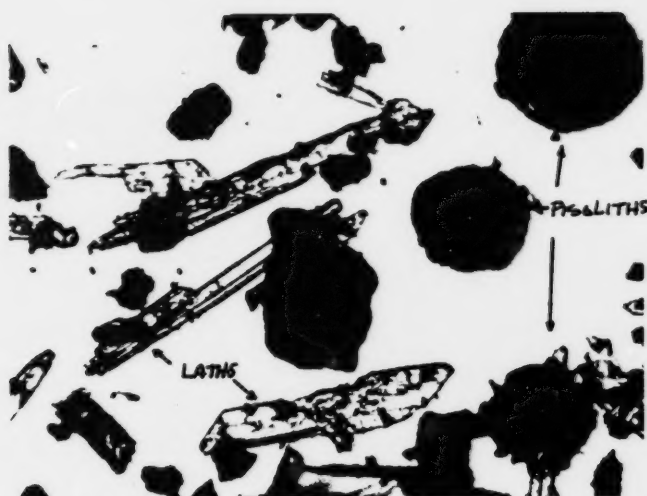


Figure 1. Photomicrograph showing gypsum laths and round pisoliths in air. The largest pisolith shown is approximately 120 microns in diameter and the longest lath is 320 microns long by 40 microns wide.

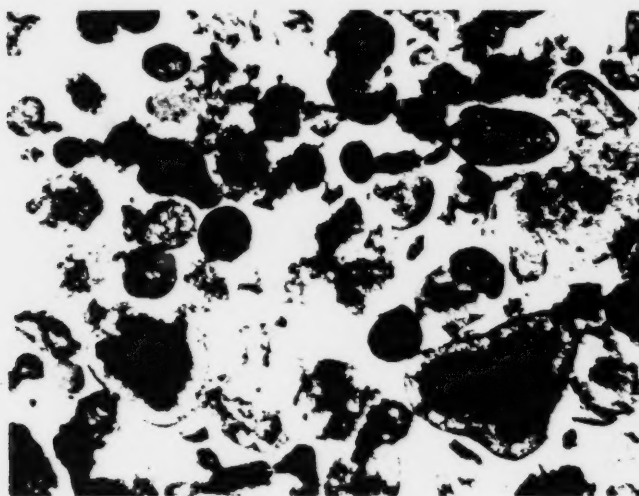
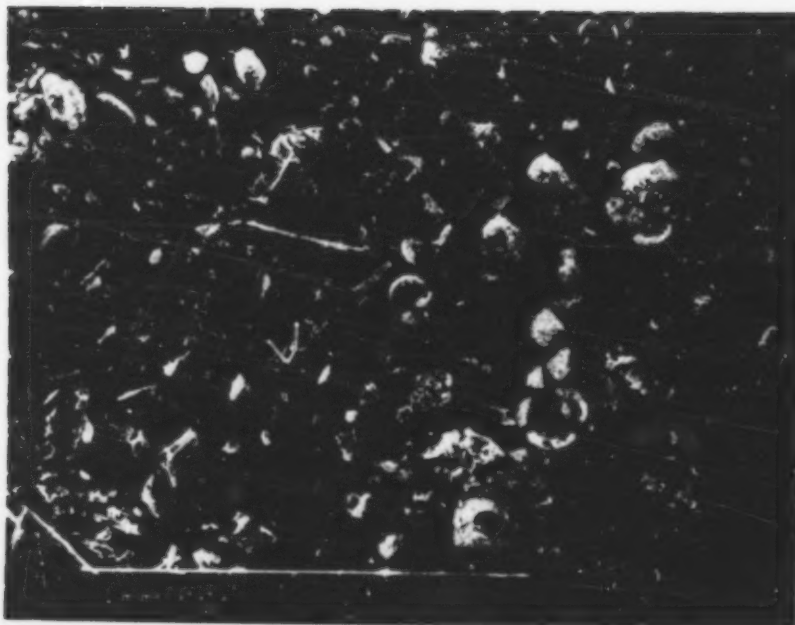


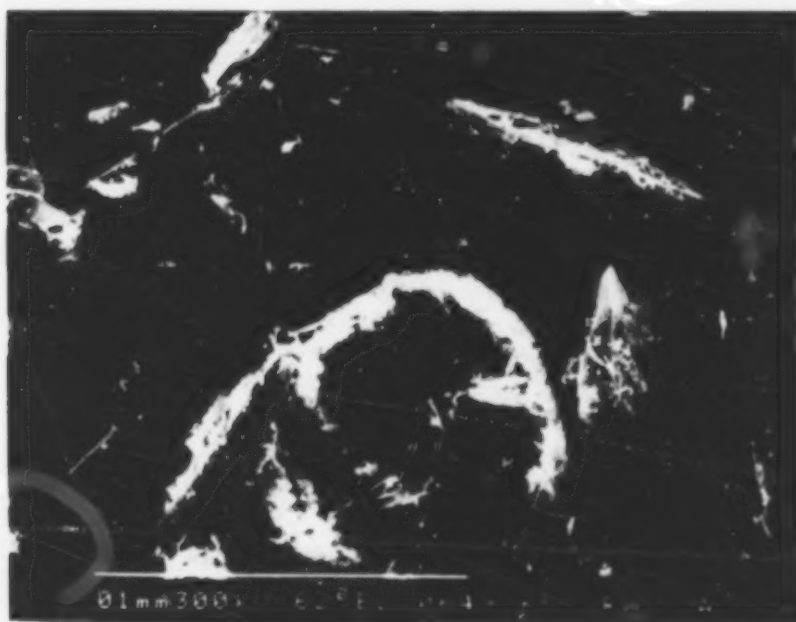
Figure 1b. Photomicrograph showing pisoliths in immersion oil. Largest pisolith (lower right) is 660 microns across. Some pisoliths show internal zoning and a thin outer rim.



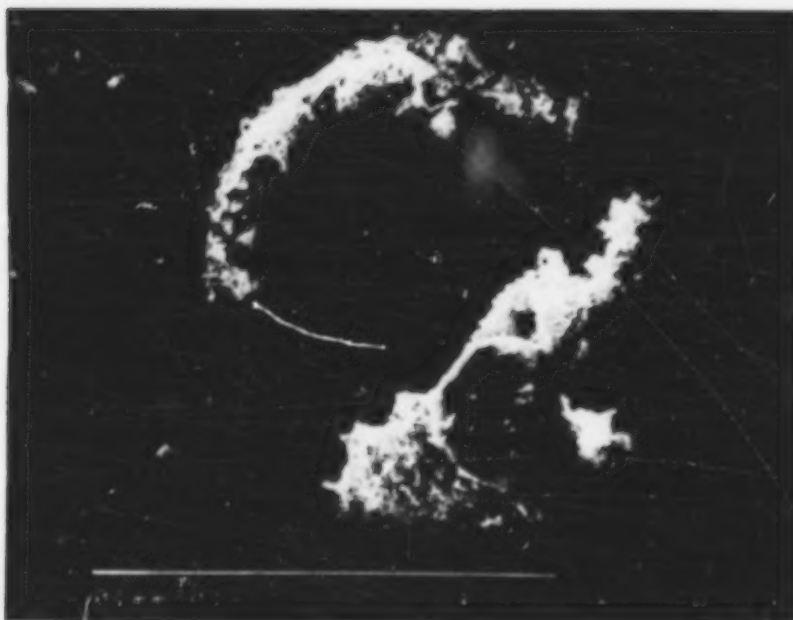
General view showing gypsum pisolites and laths and other mineral grains. (white bar = 1 mm).



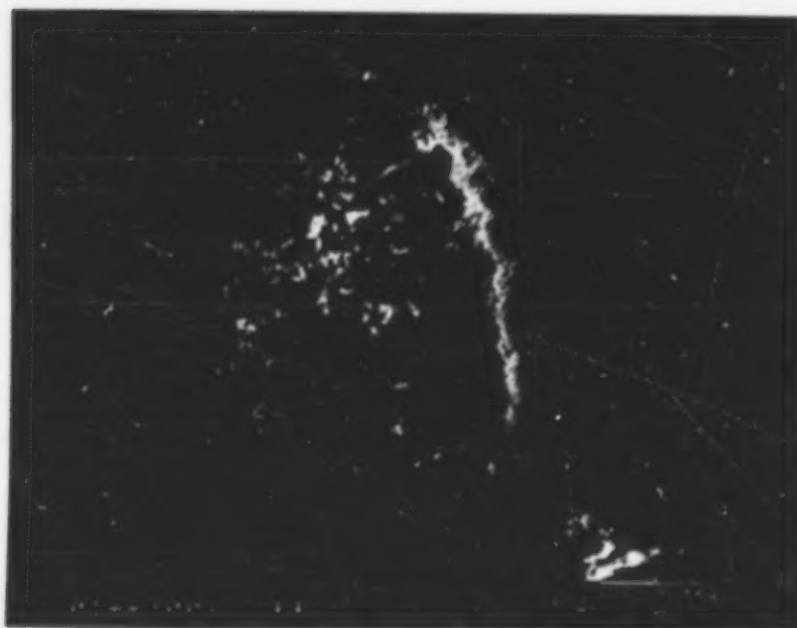
Gypsum laths and broken pisolites. (white bar = 0.1 mm).



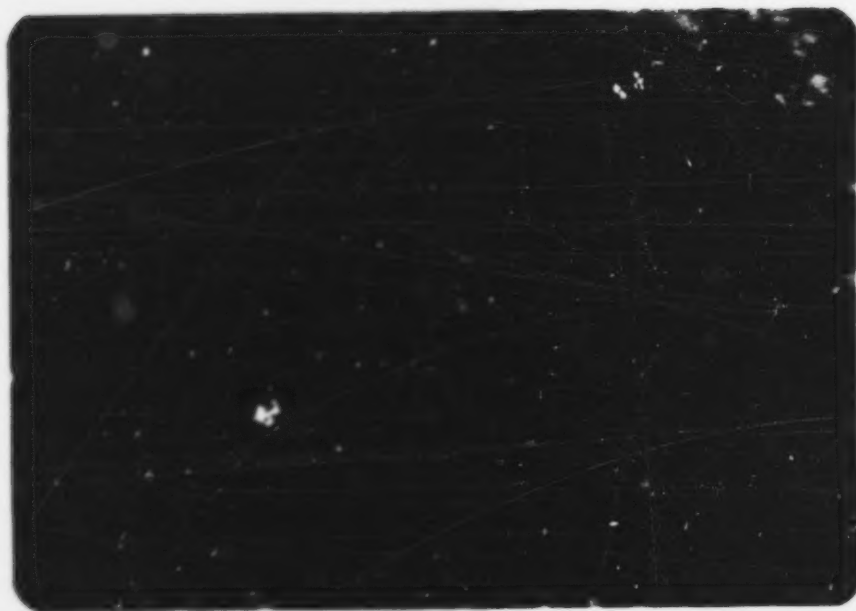
Gypsum laths and broken pisolite showing gypsum crystals inside. (white bar = 0.1 mm).



Gypsum lath on left. Silica shell of pisolite after removal of gypsum contents by dissolution in water. (white bar = 0.1 mm).



Pisolite with part of the silica shell stripped away showing gypsum crystals inside. (white bar = 0.1 mm).



General view of tailing samples showing pisolites gypsum laths, graphite flakes, quartz haematite, geothite grains, etc.



Magnified view of pisolites on a glass slide.

APPENDIX D

**REPORT ON
THERMOGRAVIMETRIC ANALYSIS
BY
B.C. RESEARCH**

BC RESEARCH

3650 Wesbrook Mall.
Vancouver, B.C.,
Canada V6S 2L2
Phone (604) 224-4331
Cable RESEARCHBC
Telex 04-507748

February 27, 1985
Our File: 4-04-276

don
H

Mr. Harvey Dew
Knight and Piesold Ltd.
Consulting Engineers
1350 United Kingdom Bldg.
409 Granville Street
Vancouver, B.C.
V6C 1T2

Dear Mr. Dew:

1602 03

Thermogravimetric analysis of your two samples of uranium tailings has been completed and the thermograms are enclosed.

The samples were air-dried overnight before testing and each sample was crushed in a mortar and well-mixed before sub-sampling. The samples were tested in duplicate with a DuPont 1090 Thermal Analyzer and a 951 Thermogravimetric Analyzer module under a constant flow of purge gas.

Sample 2-5 was heated in air at 2°C per minute from ambient to approximately 165°C. After our telephone discussion on Monday, February 25, the second sample 3-2 was heated in nitrogen at 2°C per minute up to 160°C, at which point the heating rate was increased to 15°C per minute and heating was continued to 550°C on the first test and to 625°C on the second test.

Two thermograms are enclosed for each test; the first plots weight percent and temperature against time, and the second shows weight percent and the first derivative of weight percent versus time. Analysis of each transition is printed on the first thermogram.

The duplicates appear to be the same, within experimental error, up to 165°C. The small weight gain, which occurred between 400°C and 500°C in the first test of the second sample, did not happen in the second test. I have no explanation for this event. The transition occurring at 105°C to 110°C in each test may possibly be two distinct losses, judging by the shape of the derivative curve. It might be possible to separate these more clearly with a very slow heating rate in this temperature region, say 0.1 or 0.2°C/min.

BC
RESEARCH

- 2 -

I hope that these tests provide the information you require. The data are stored in disk memory and can be replotted, or any portion can be expanded, on request. Please call me if you have any questions.

Yours very truly,

B.C. RESEARCH

Erin Skelton

(Mrs.) Erin S. Skelton
Chemical Technology Division

ESS:amp
encls.

Sample: K+P 2-5

Size: 43.35 mg

Rate: 2 DEG/MIN IN AIR

Program: TGA Analysis V1.0

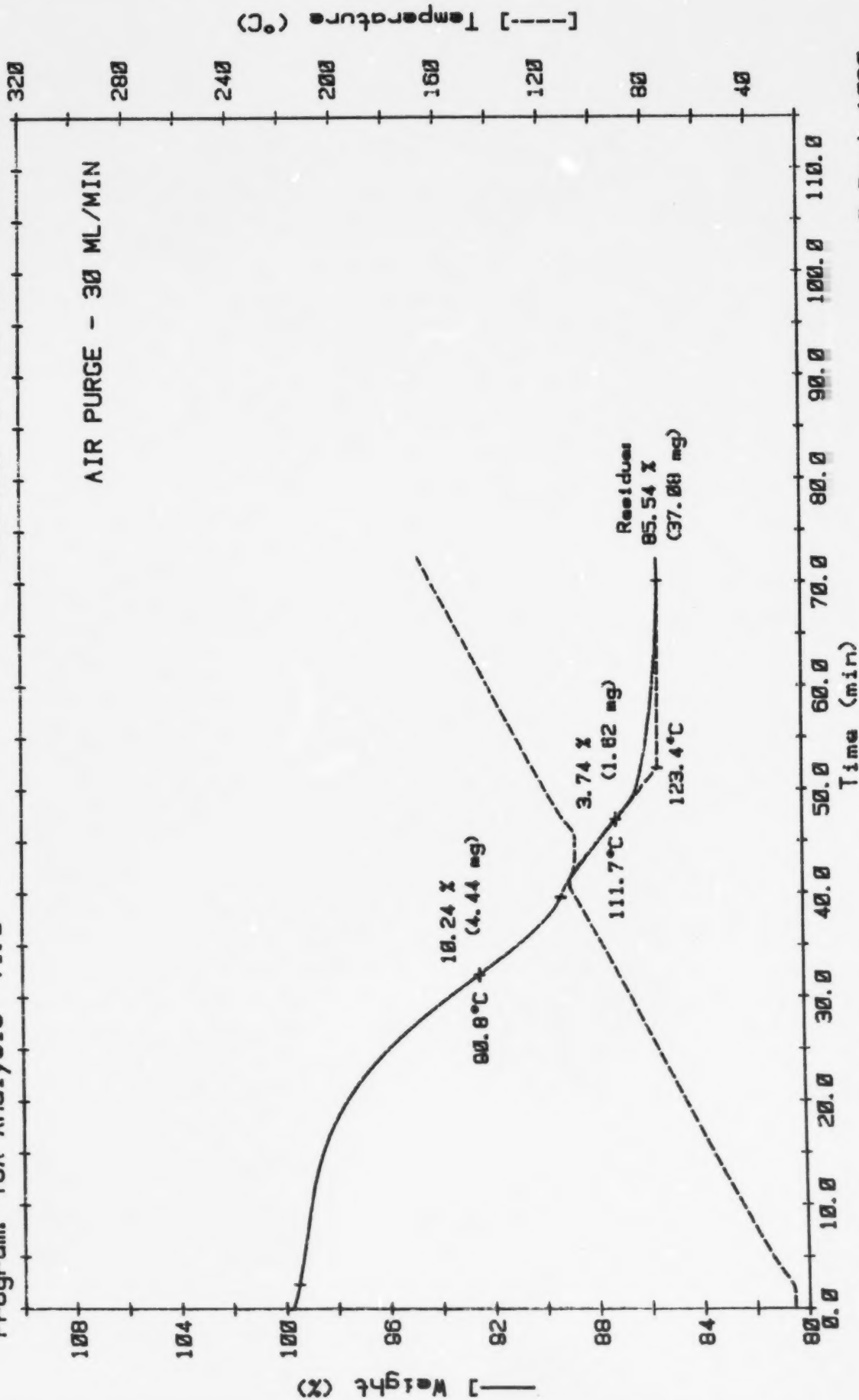
Date: 25-Feb-85 Time: 14:21:52

File: K+P.03 MISC TEST XII

Operator: ERIN

Plotted: 27-Feb-85 9:46:47

TGA



Sample: K+P 2-5

Size: 43.35 mg

Rate: 2 DEG/MIN IN AIR

Program: TGA Analysis V1.0

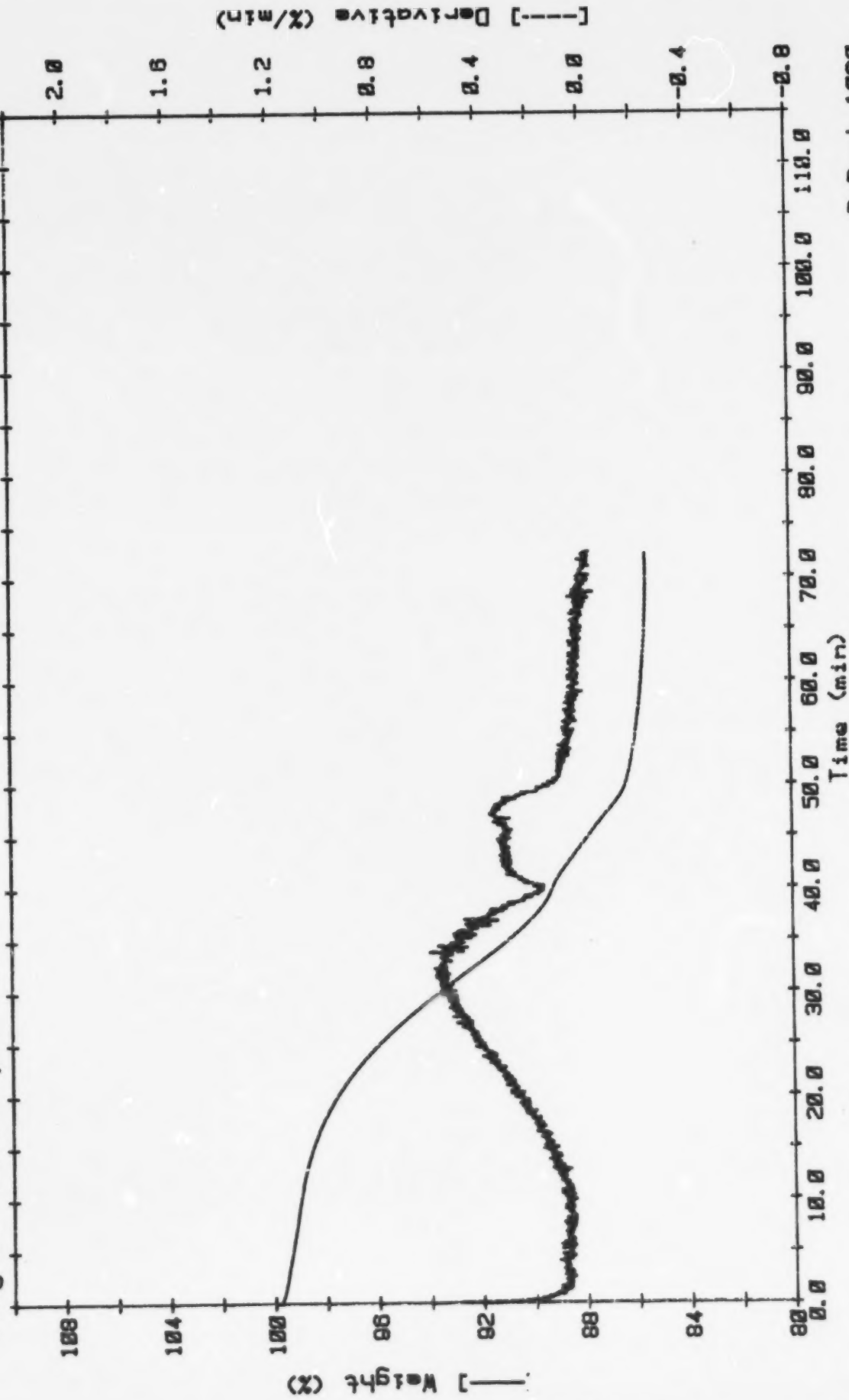
TGA

Date: 25-Feb-85 Time: 14:21:52

File: K+P.03 MISC TEST XII

Operator: ERIN

Plotted: 27-Feb-85 13:20:47



DuPont 1090

Sample: K+P 2-5

Size: 43.85 mg

Rate: 2 DEG/MIN IN AIR

Program: TGA Analysis V1.0

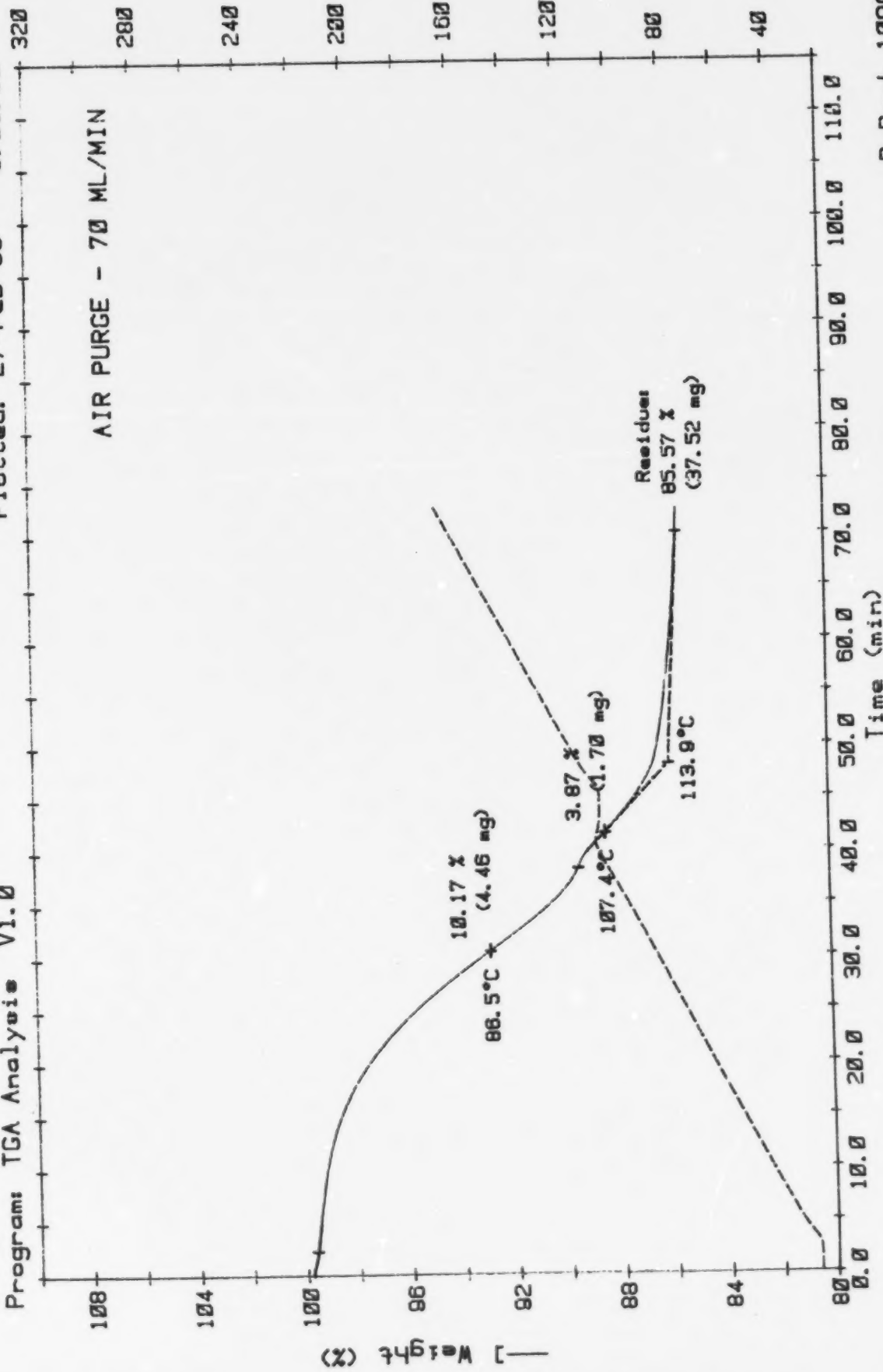
TGA

Date: 25-Feb-85 Time: 11:36:29

File: K+P.02 MISC TEST XII

Operator: ERIN

Plotted: 27-Feb-85 9:21:52



Sample: K+P 2-5

Size: 43.85 mg

Rate: 2 DEG/MIN IN AIR

Program: TGA Analysis V1.0

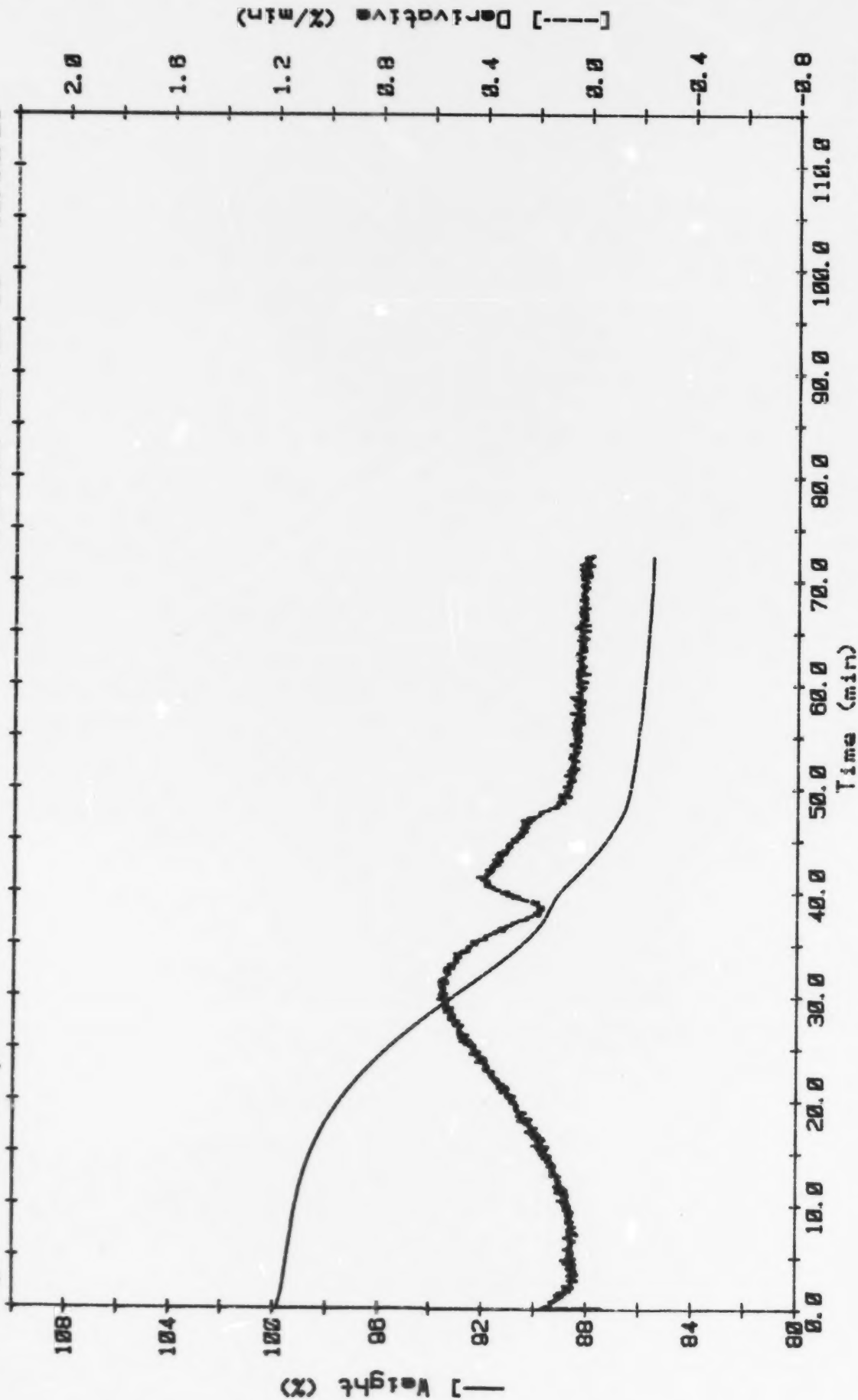
TGA

Date: 25-Feb-85 Time: 11:36:29

File: K+P.02 MISC TEST XII

Operator: ERIN

Plotted: 27-Feb-85 13:33:01

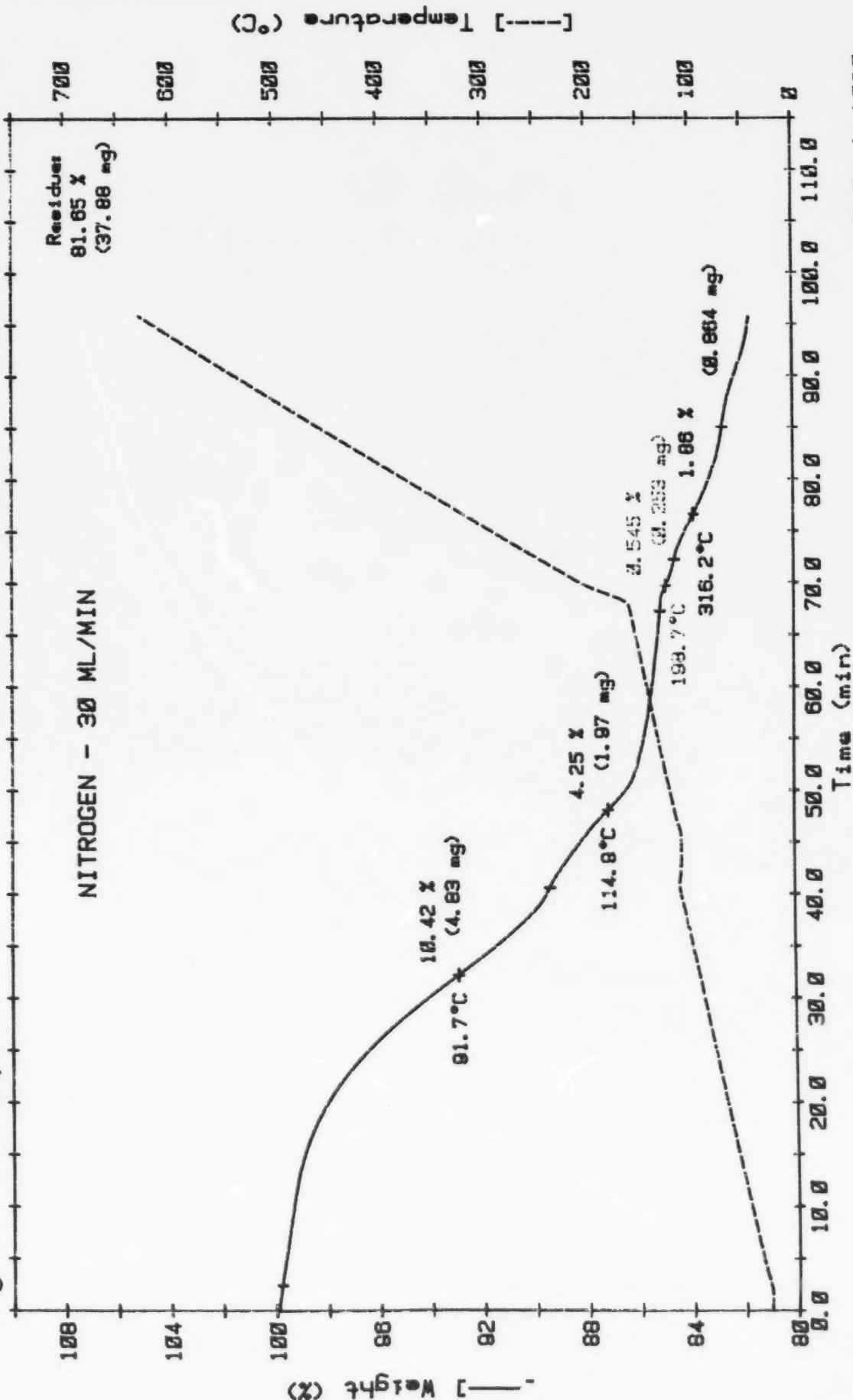


DuPont 1090

Date: 26-Feb-85 Time: 13:23:08
 File: K+P.05 MISC TEST XII
 Operator: ERIN
 Plotted: 27-Feb-85 10:54:20

Sample: K+P 3-2
 Size: 46.40 mg
 Rate: 2+15 DEG/MIN IN N2
 Program: TGA Analysis V1.0

TGA



Sample: K+P 3-2

Size: 46.40 mg

Rate: 2+15 DEG/MIN IN N2

Program: TGA Analysis V1.0

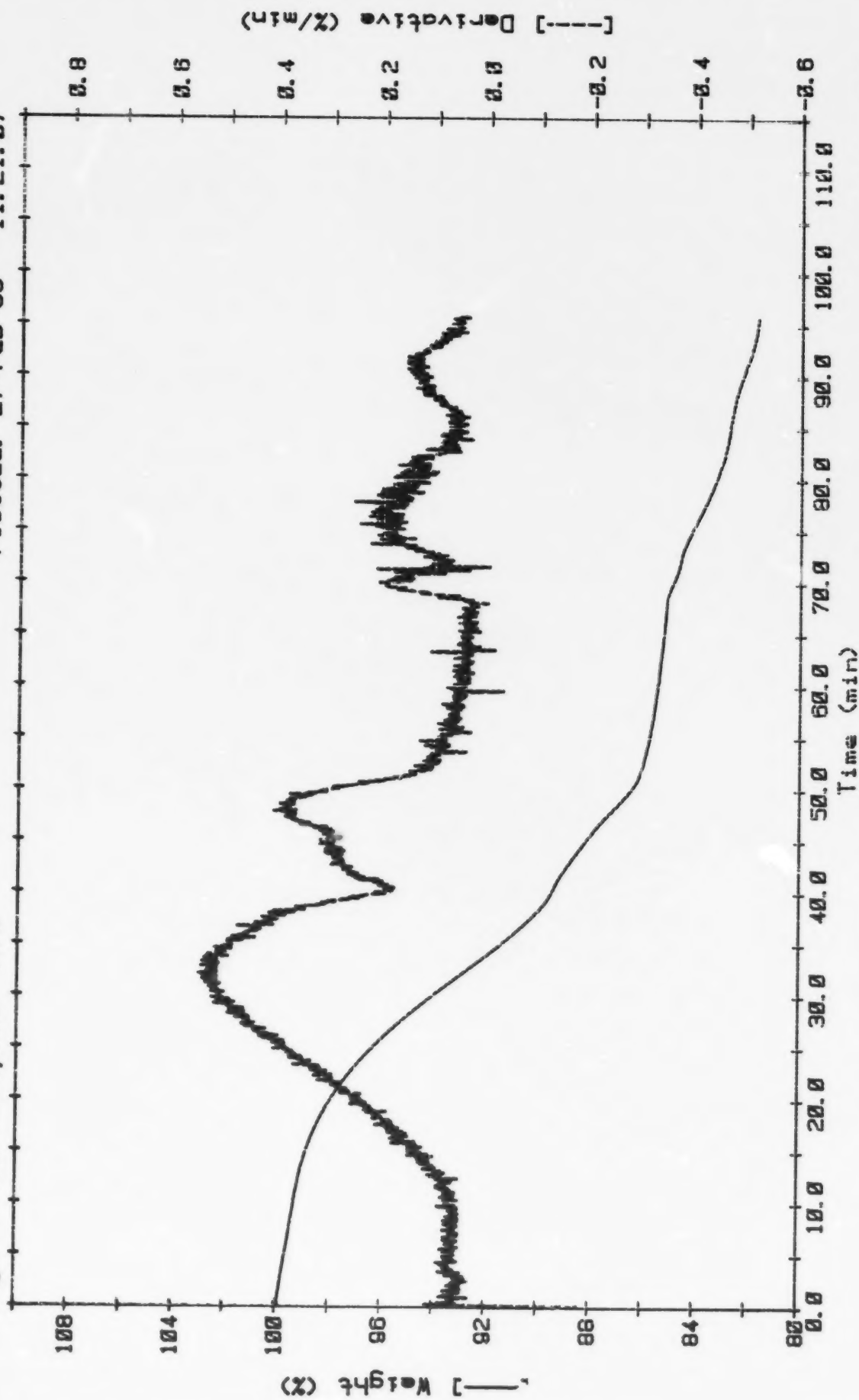
TGA

Date: 26-Feb-85 Time: 13:23:08

File: K+P.05 MISC TEST XII

Operator: ERIN

Plotted: 27-Feb-85 11:21:07



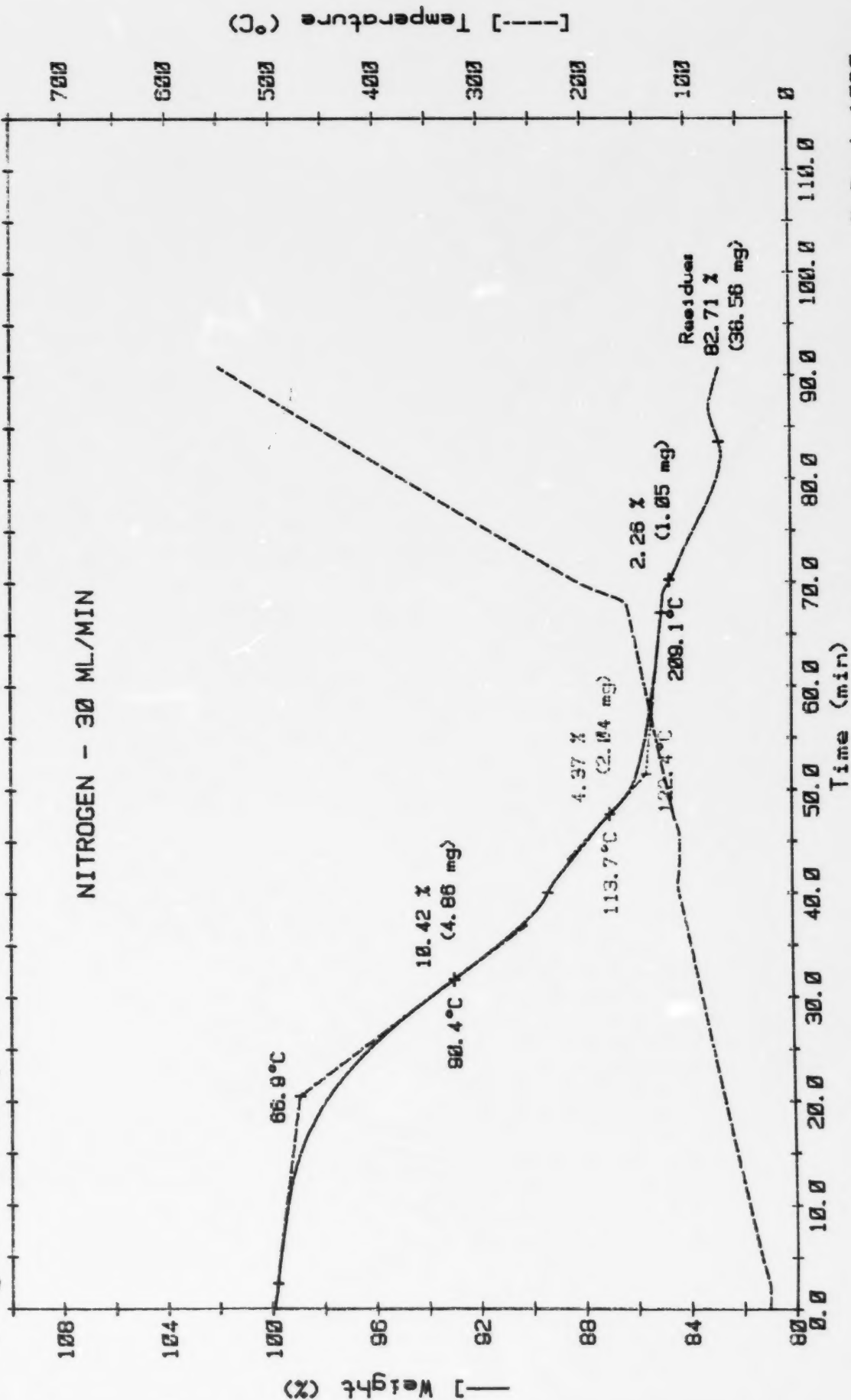
DuPont 1090

Date: 26-Feb-85 Time: 9:38:54
 File: K+P.04 MISC TEST XII
 Operator: ERIN
 Plotted: 27-Feb-85 10:03:39

Sample: K+P 3-2
 Size: 46.62 mg
 Rate: 2+15 DEG/MIN IN N2
 Program: TGA Analysis V1.0

TGA

NITROGEN - 30 ML/MIN



Sample: K+P 3-2

Size: 46.62 mg

Rate: 2+15 DEG/MIN IN N2

Program: TGA Analysis V1.0

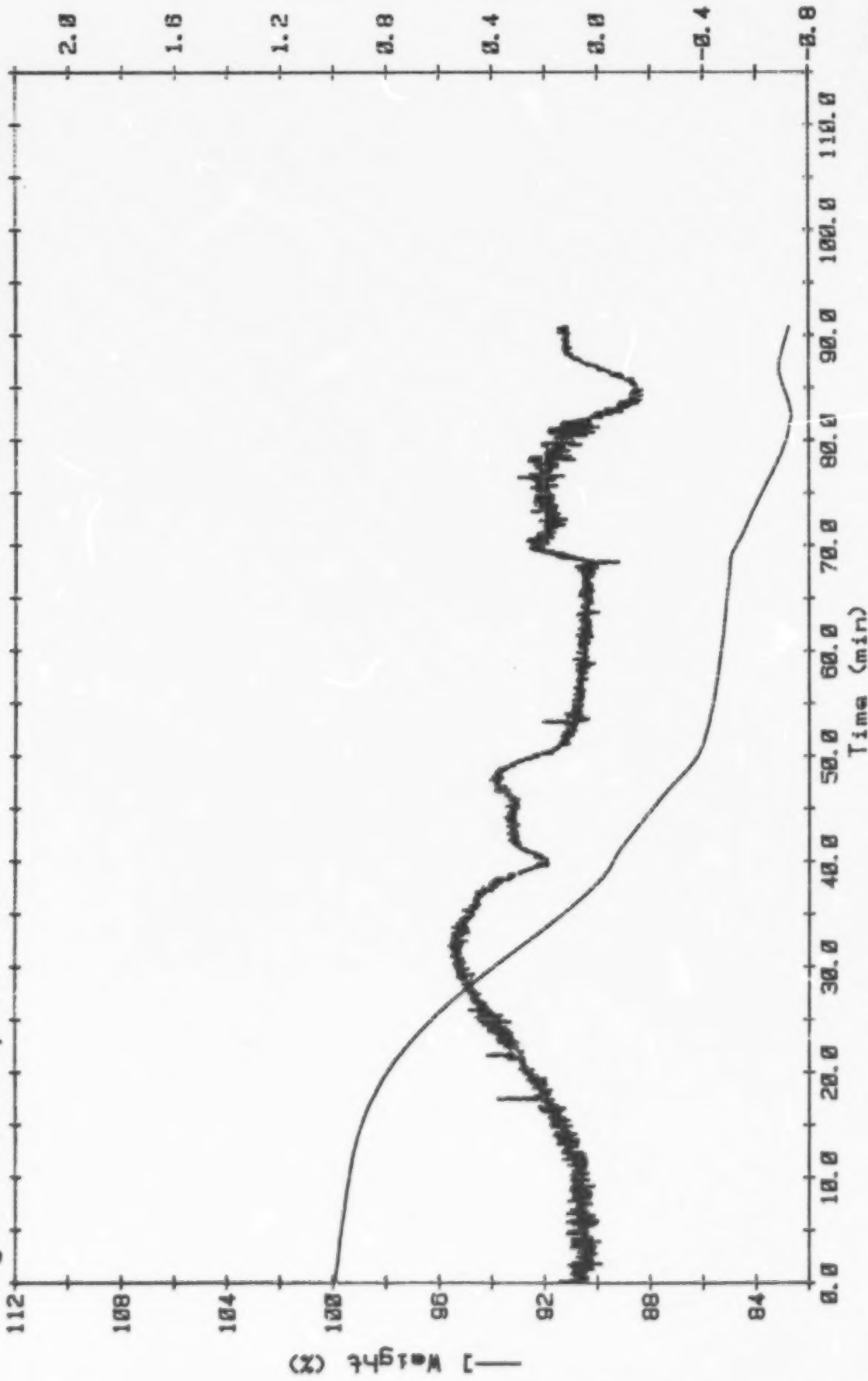
TGA

Date: 26-Feb-85 Time: 9:38:54

File: K+P.04 MISC TEST XII

Operator: ERIN

Plotted: 27-Feb-85 11:37:27



DuPont 1090

BC RESEARCH

3650 Westbrook Mall,
Vancouver, B.C.,
Canada V6S 2L2
Phone (604) 224-4331
Cable RESEARCHBC
Telex 04-507748

March 26, 1985
Our File: 4-04-276

Mr. Harvey Dew
Knight and Piesold Ltd.
Consulting Engineers
1350 United Kingdom Bldg.
409 Granville Street
Vancouver, B.C.
V6C 1T2

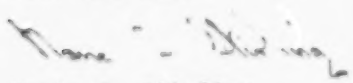
Dear Mr. Dew:

I am enclosing the replotted thermograms, over the temperature range 80-110°C, for the two samples of uranium tailings (2-5 and 3-2). Portions of each sample are being returned to you.

I hope that this information is useful to you. Please call if you have any questions.

Yours sincerely,

B.C. RESEARCH


Marie T. Stirling
Chemical Technology Division

MTS:amp
encls.

Sample: K+P 2-5

Size: 43.35 mg

Rate: 2 DEG/MIN IN AIR

Program: TGA Analysis V1.0

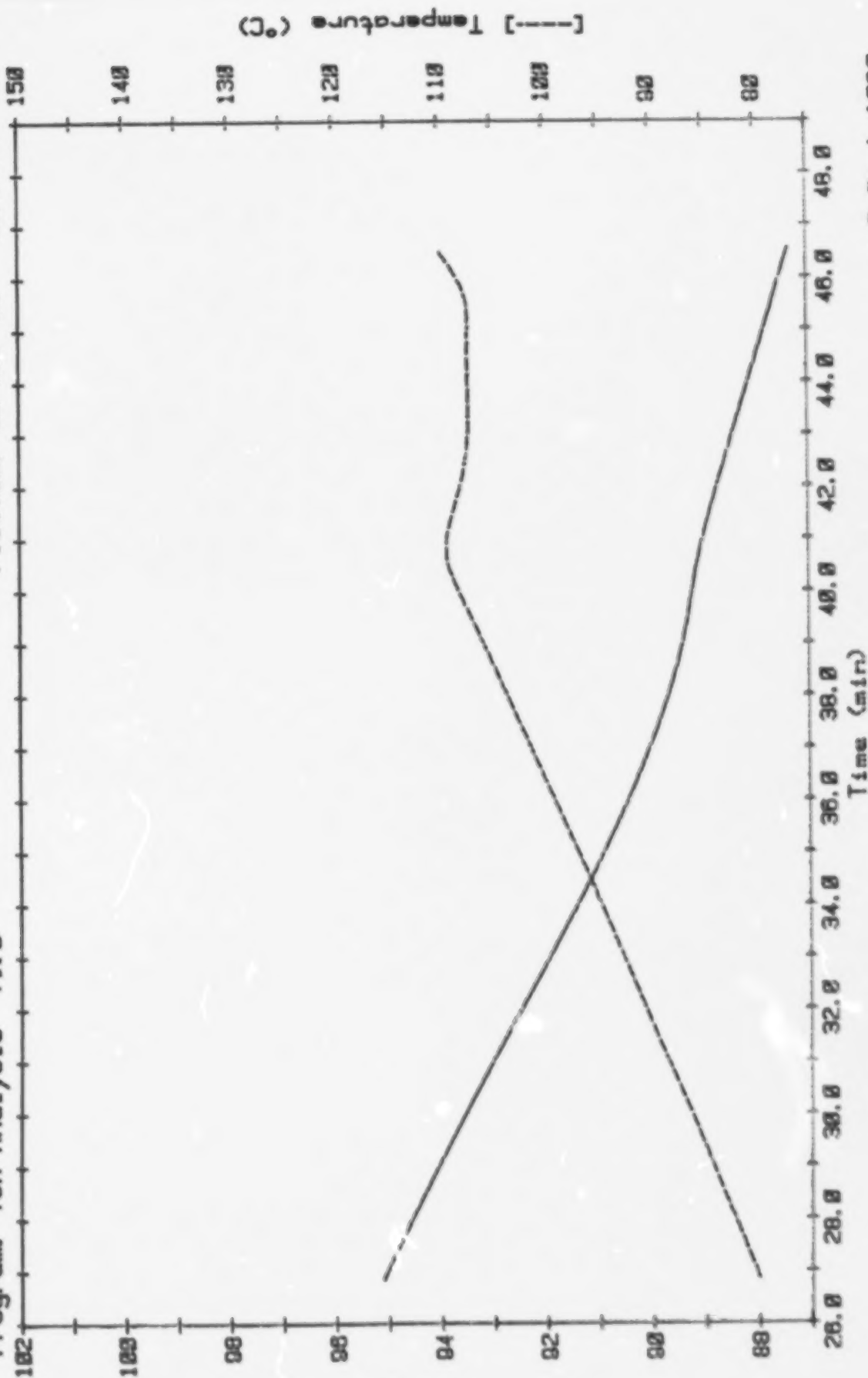
Date: 25-Feb-85 Time: 14:21:52

File: K+P.03 MISC TEST XII

Operator: ERIN

Plotted: 26-Mar-85 12:34:12

TGA



DuPont 1090

Sample: K+P 2-5

Size: 43.35 mg

Rate: 2 DEG/MIN IN AIR

Program: TGA Analysis V1.0

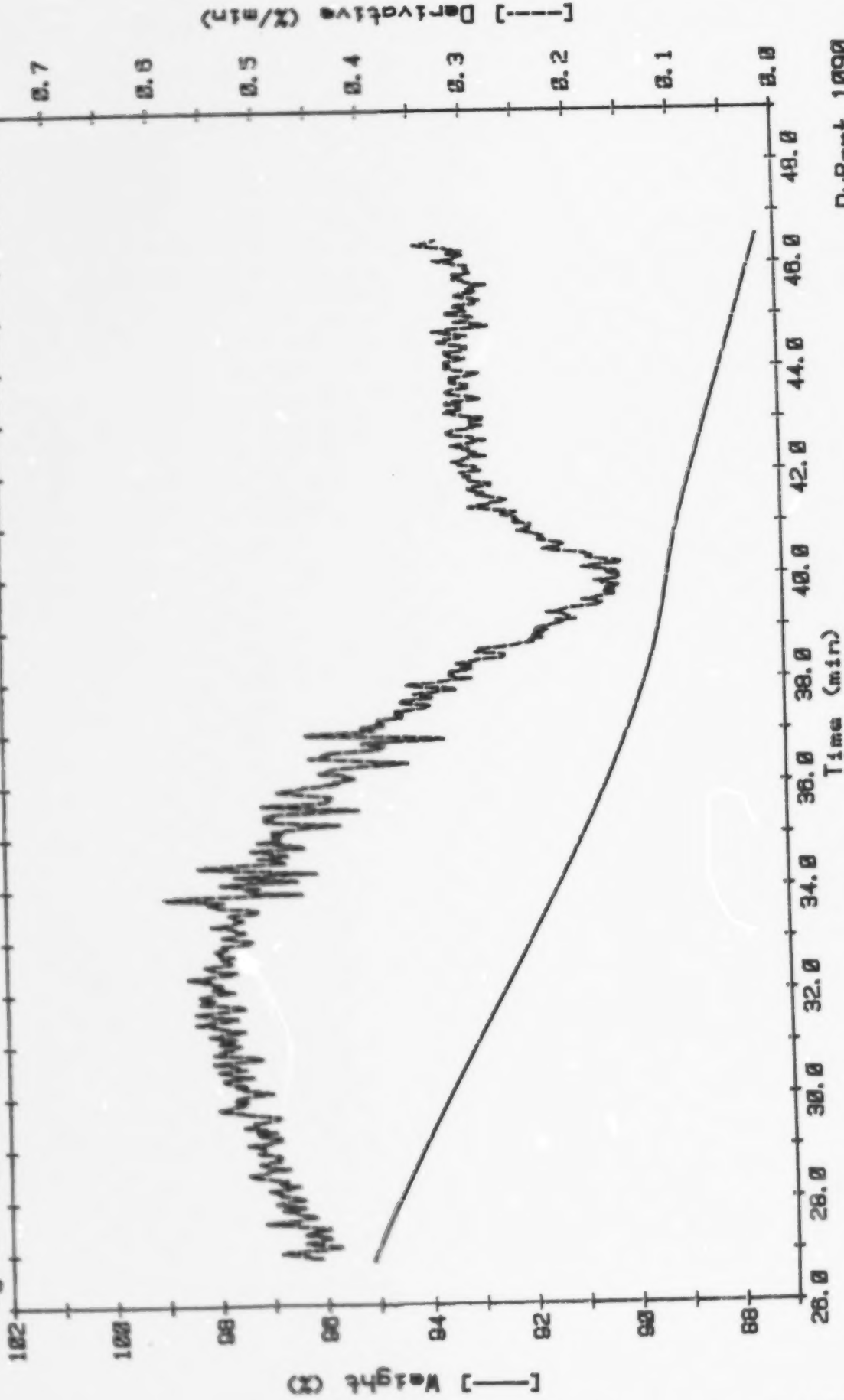
TGA

Date: 25-Feb-85 Time: 14:21:52

File: K+P.03 MISC TEST XII

Operator: ERIN

Plotted: 28-Mar-85 12:42:51



Time (min)

DuPont 1090

Samples K+P 2-5

Size: 43.35 mg

Rate: 2 DEG/MIN IN AIR

Program: TGA Analysis V1.0

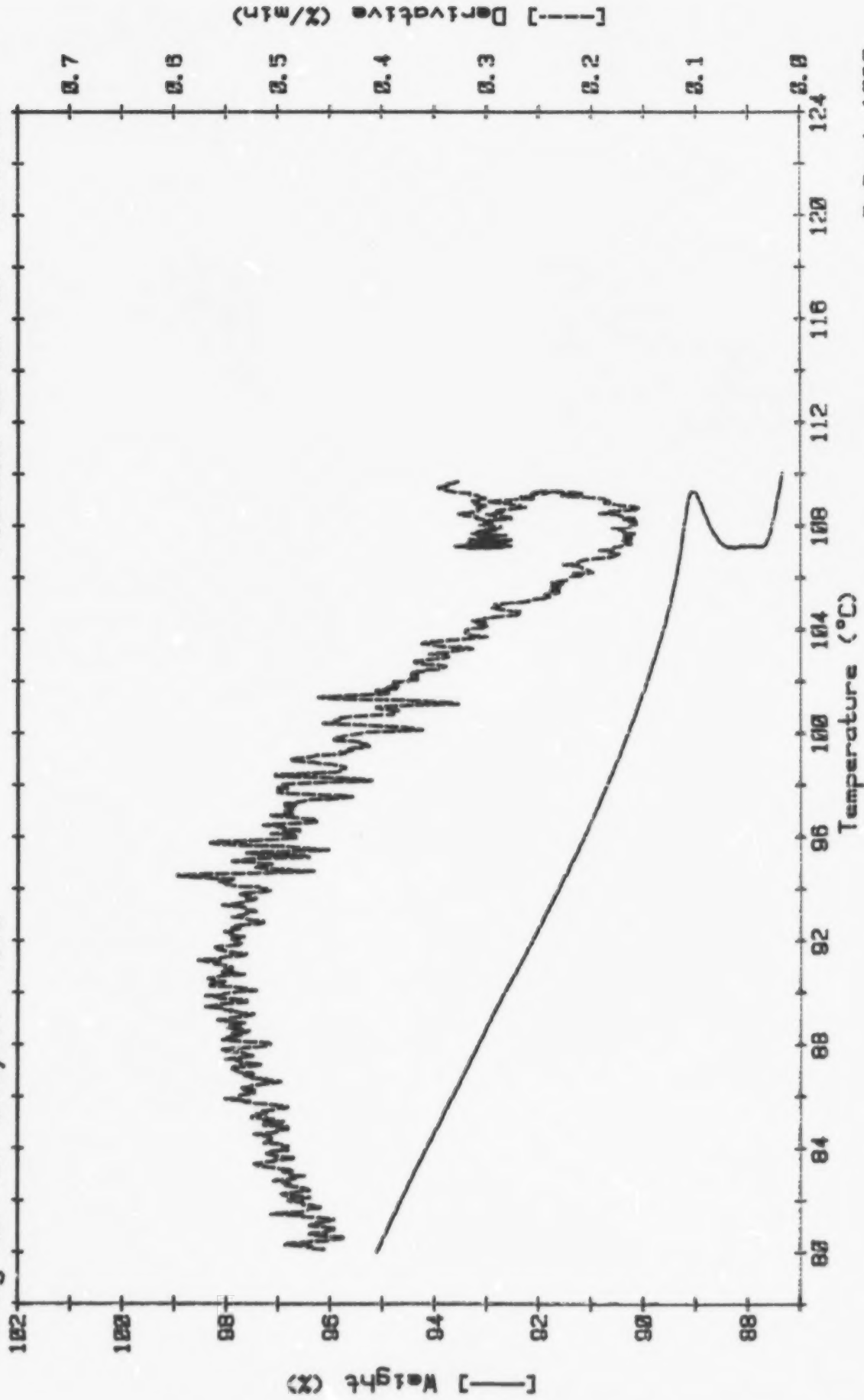
TGA

Date: 25-Feb-85 Time: 14:21:52

File: K+P.03 MISC TEST XII

Operator: ERIN

Plotted: 26-Mar-85 12:51:44



DuPont 1090

Sample: K+P 2-5

Size: 43.85 mg

Rate: 2 DEG/MIN IN AIR

Program: TGA Analysis V1.0

TGA

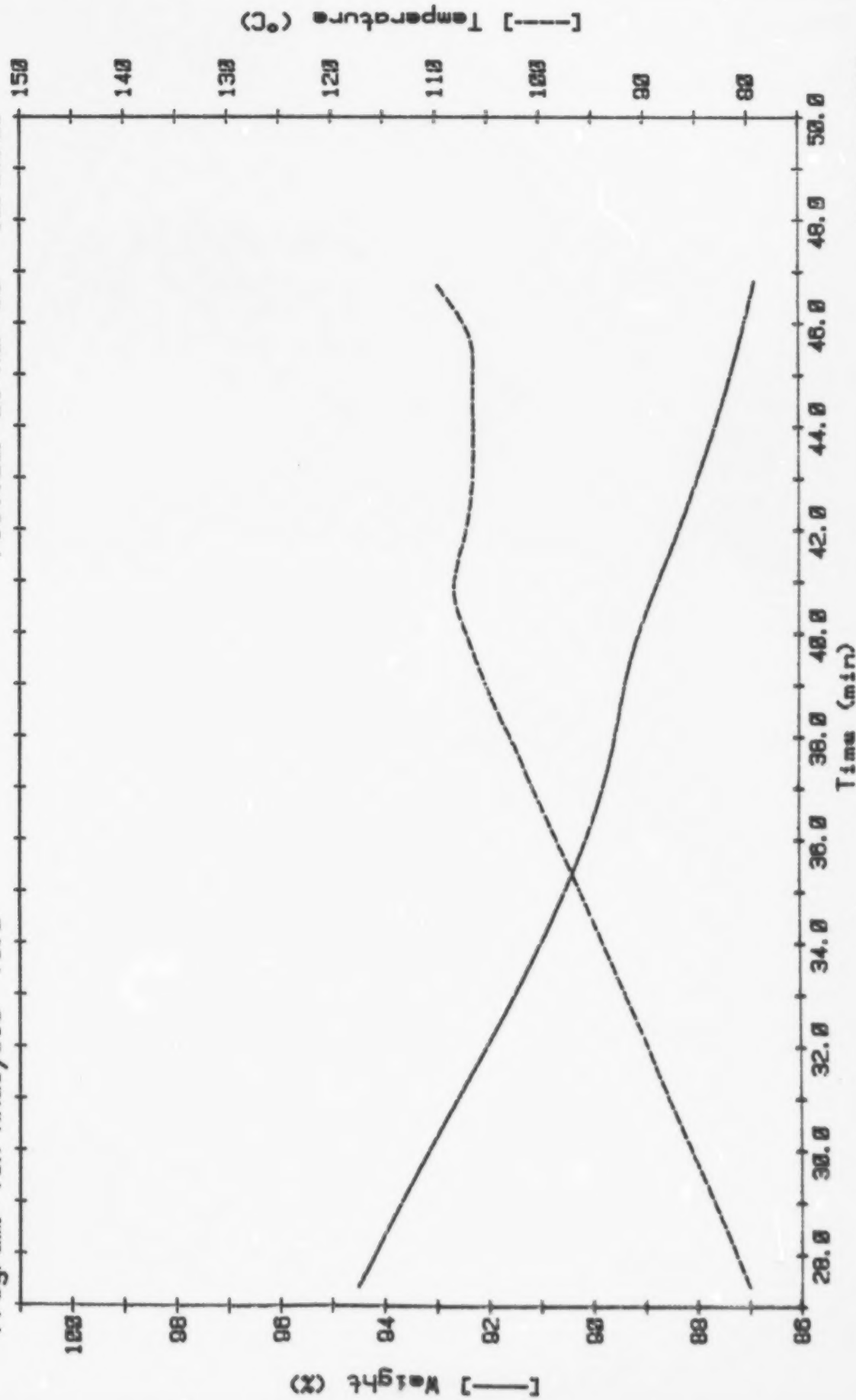
Date: 25-Feb-85

Time: 11:36:29

File: K+P.02 MISC TEST XII

Operator: ERIN

Plotted: 26-Mar-85 12:28:21



Samples K+P 2-5

Size: 43.85 mg

Rate: 2 DEG/MIN IN AIR

Program: TGA Analysis V1.0

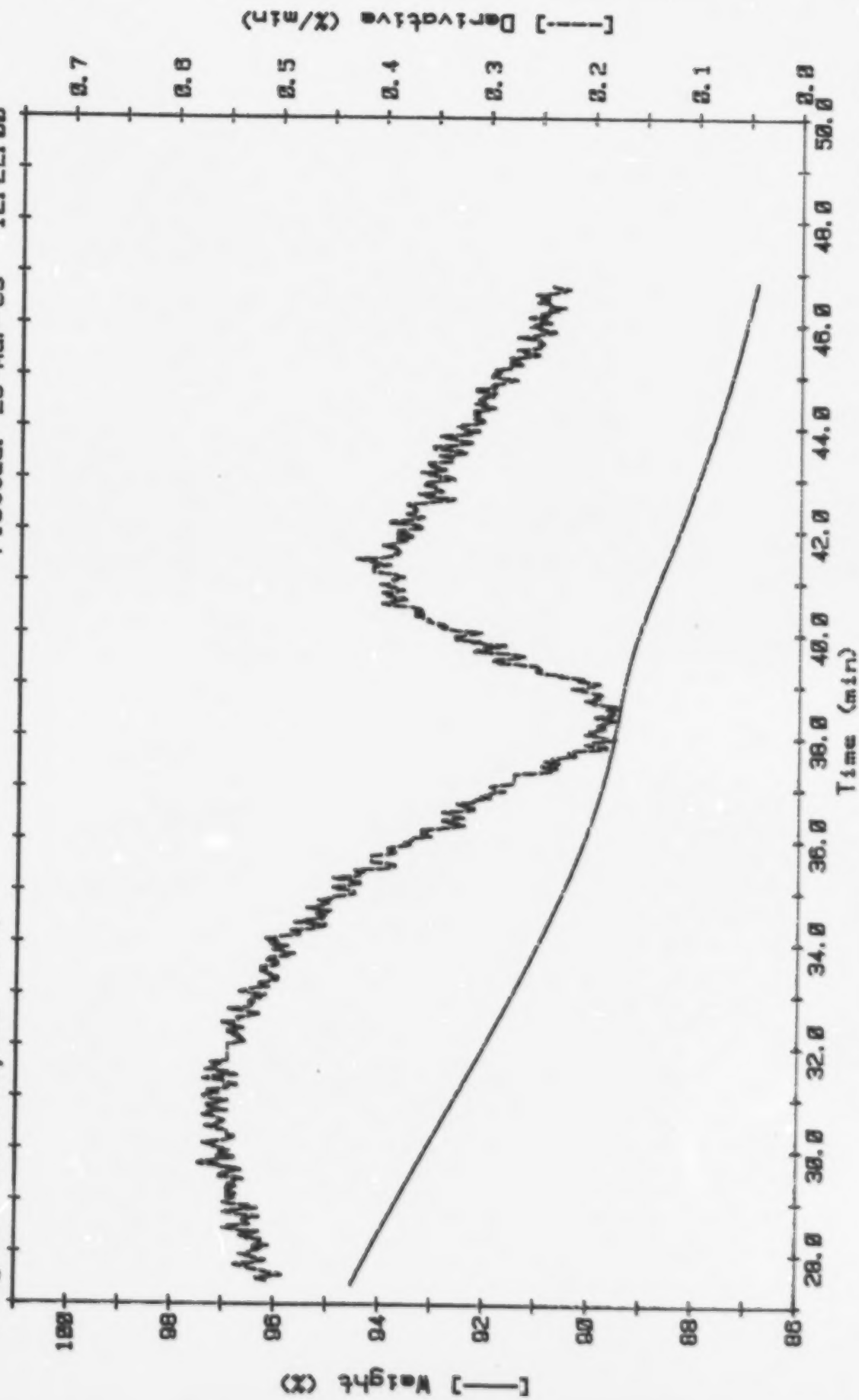
TGA

Date: 25-Feb-85 Time: 11:36:29

File: K+P.02 MISC TEST XII

Operator: ERIN

Plotted: 26-Mar-85 12:22:00



DuPont 1090

Sample: K+P 2-5

Size: 43.85 mg

Rate: 2 DEG/MIN IN AIR

Program: TGA Analysis V1.0

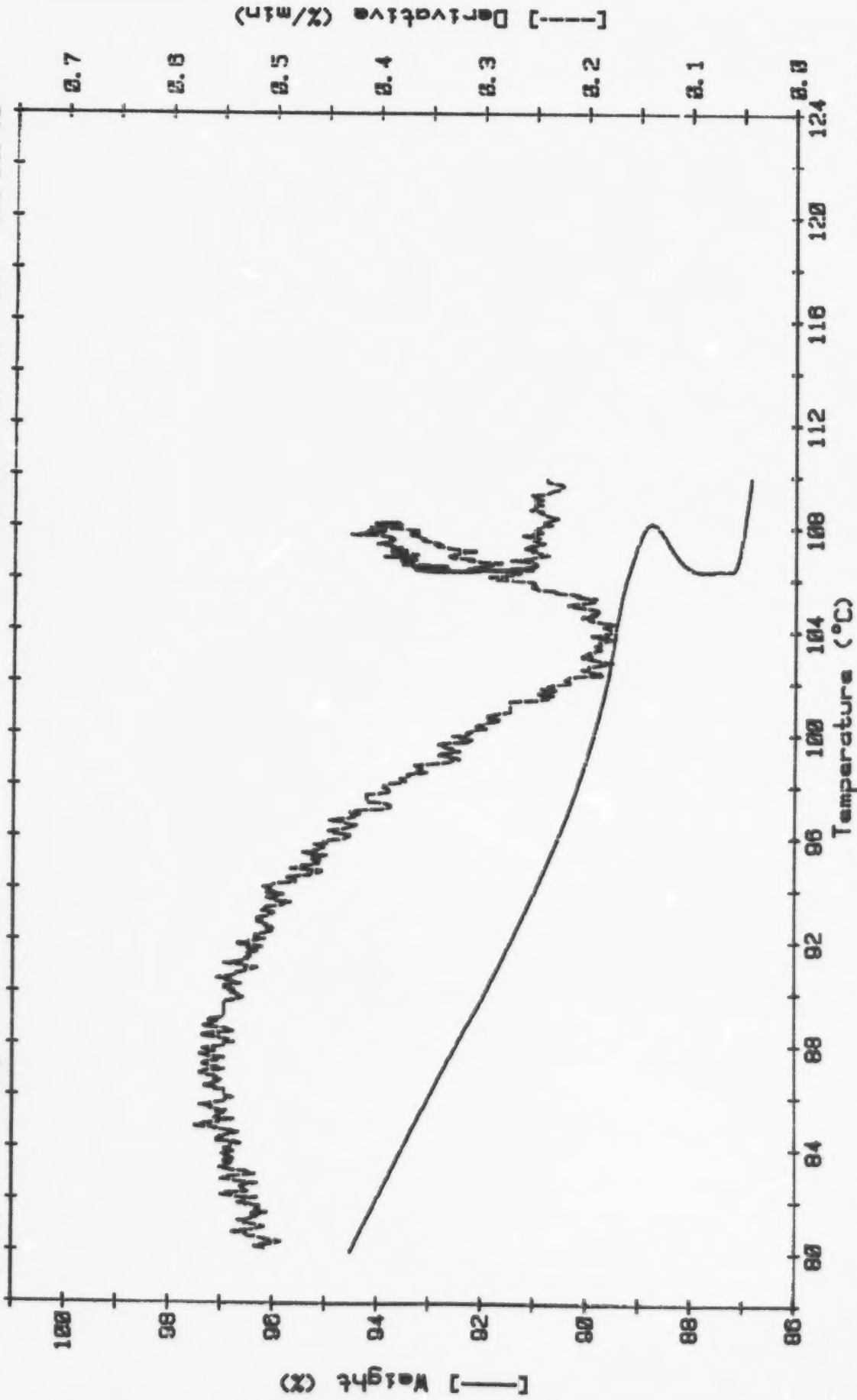
TGA

Date: 25-Feb-85 Time: 11:36:29

File: K+P.02 MISC TEST XII

Operator: ERIN

Plotted: 26-Mar-85 12:13:49



Sample: K+P 3-2

Size: 48.40 mg

Rate: 2+15 DEG/MIN IN N2

Program: TGA Analysis V1.0

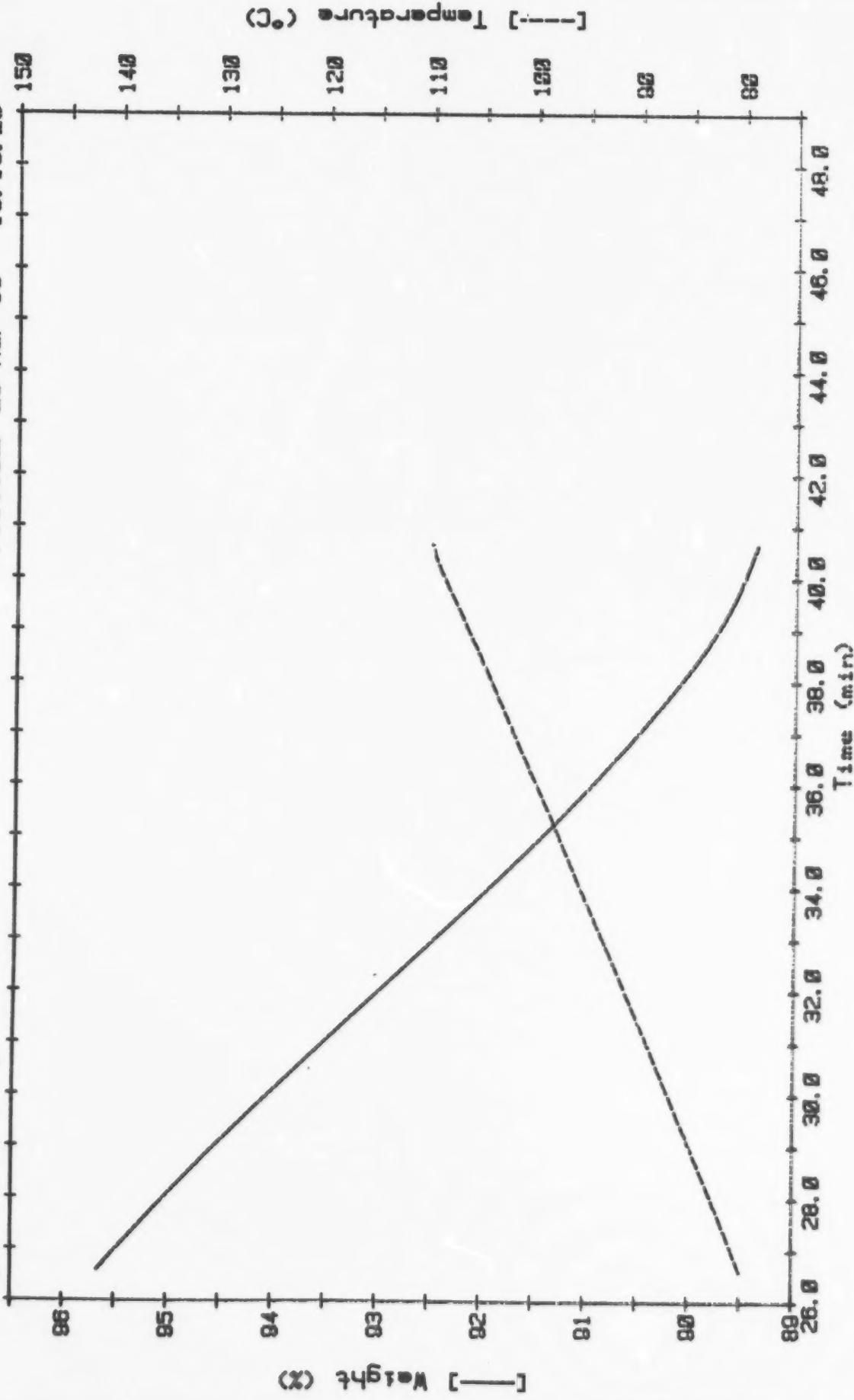
TGA

Date: 26-Feb-85 Time: 13:23:08

File: K+P.05 MISC TEST XII

Operator: ERIN

Plotted: 26-Mar-85 13:19:25



Sample: K+P 3-2

Size: 46.40 mg

Rate: 2+15 DEG/MIN IN N2

Program: TGA Analysis V1.0

Date: 26-Feb-85

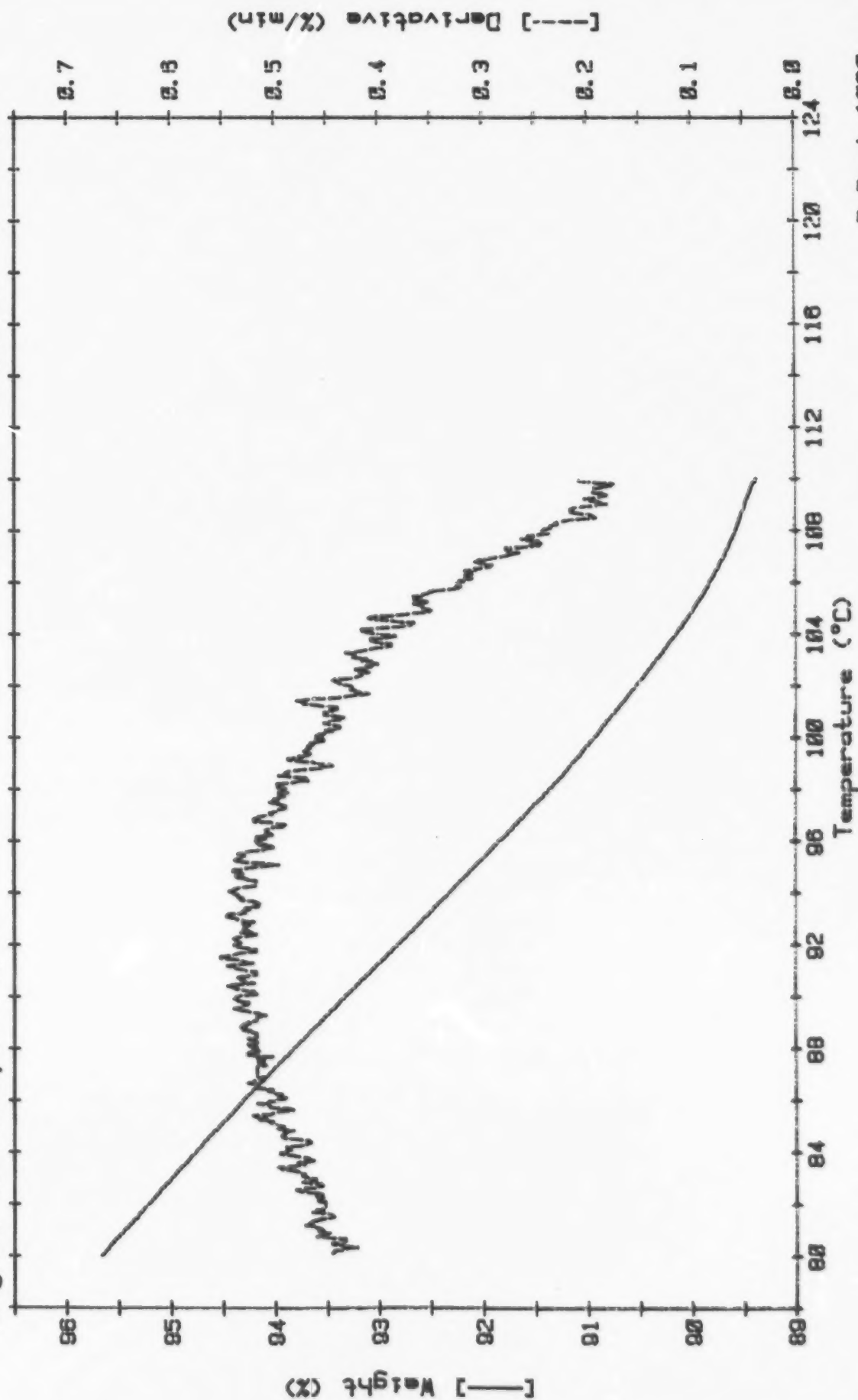
File: K+P.05 MISC TEST XII

Operator: ERIN

Plotted: 26-Mar-85 13:33:45

Time: 13:23:08

TGA



Samples K+P 3-2

Size: 46.40 mg

Rate: 2+15 DEG/MIN IN N2

Program: TGA Analysis V1.0

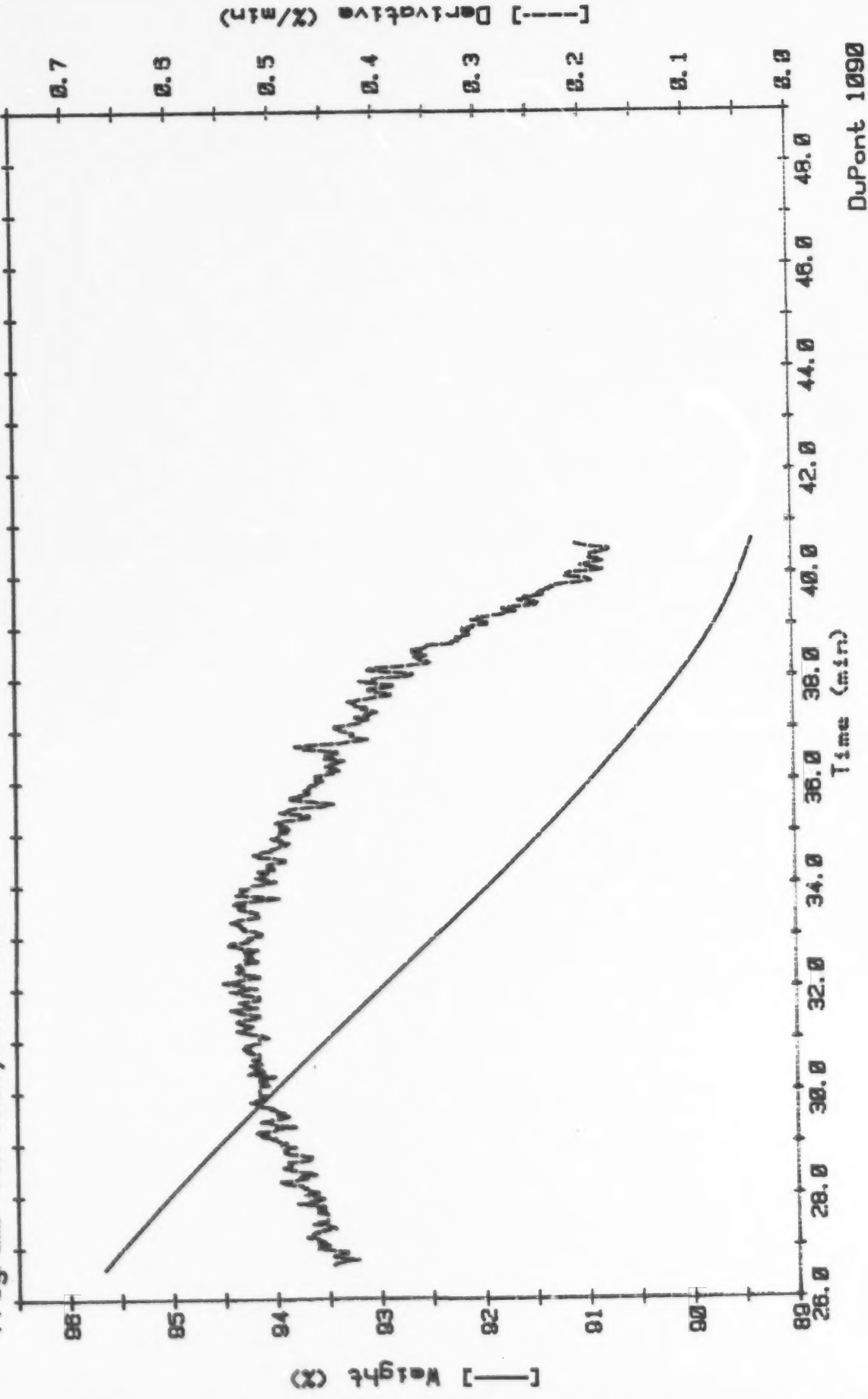
TGA

Date: 26-Feb-85 Time: 13:23:08

File: K+P.05 MISC TEST XII

Operator: ERIN

Plotted: 26-Mar-85 13:26:52



DuPont 1090

Sample: K+P 3-2

Size: 46.62 mg

Rate: 2+15 DEG/MIN IN N2

Program: TGA Analysis V1.0

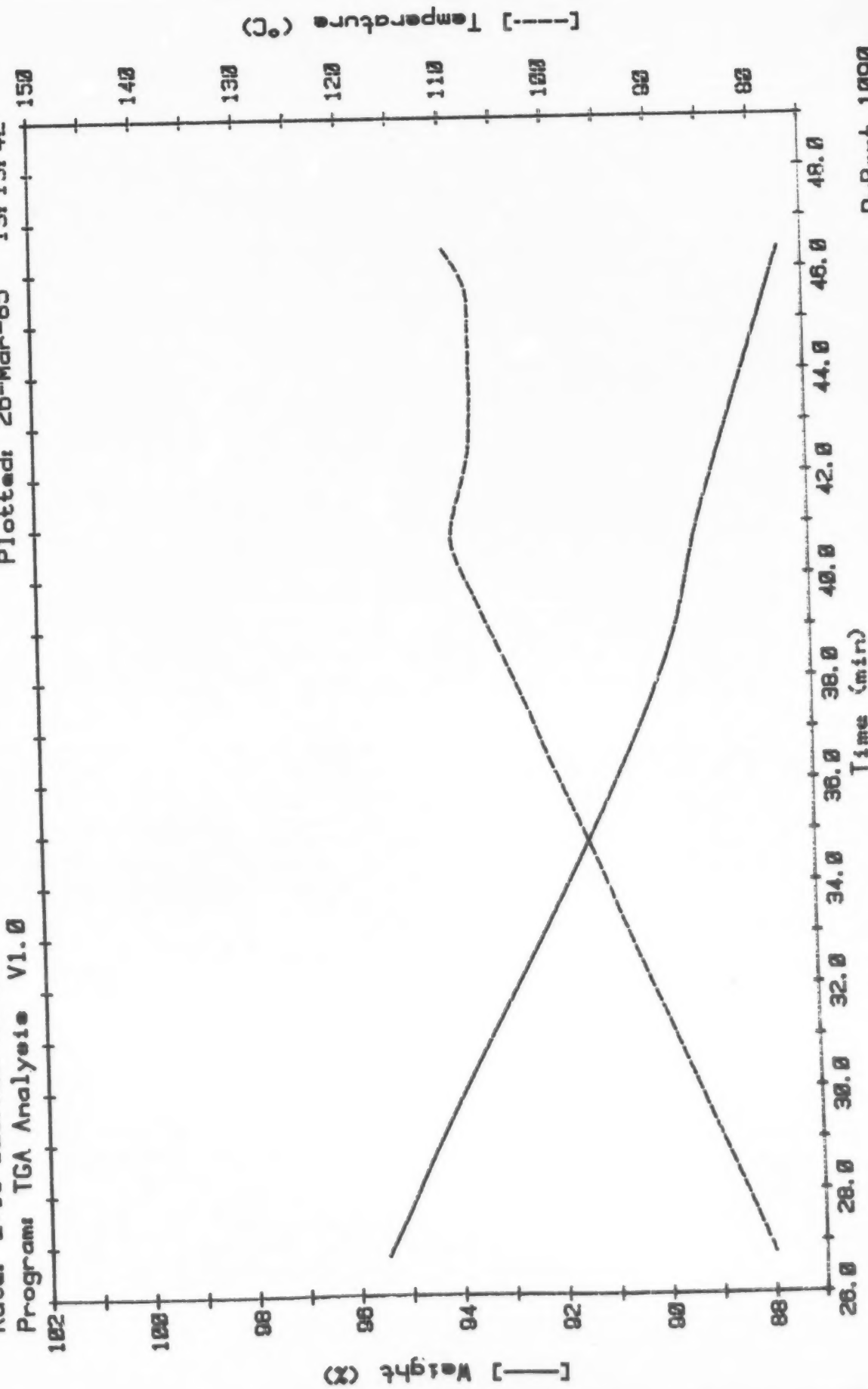
TGA

Date: 26-Feb-85 Time: 9:38:54

File: K+P.04 MISC TEST XII

Operator: ERIN

Plotted: 26-Mar-85 13:13:42



Sample: K+P 3-2

Size: 46.62 mg

Rate: 2+15 DEG/MIN IN N2

Program: TGA Analysis V1.0

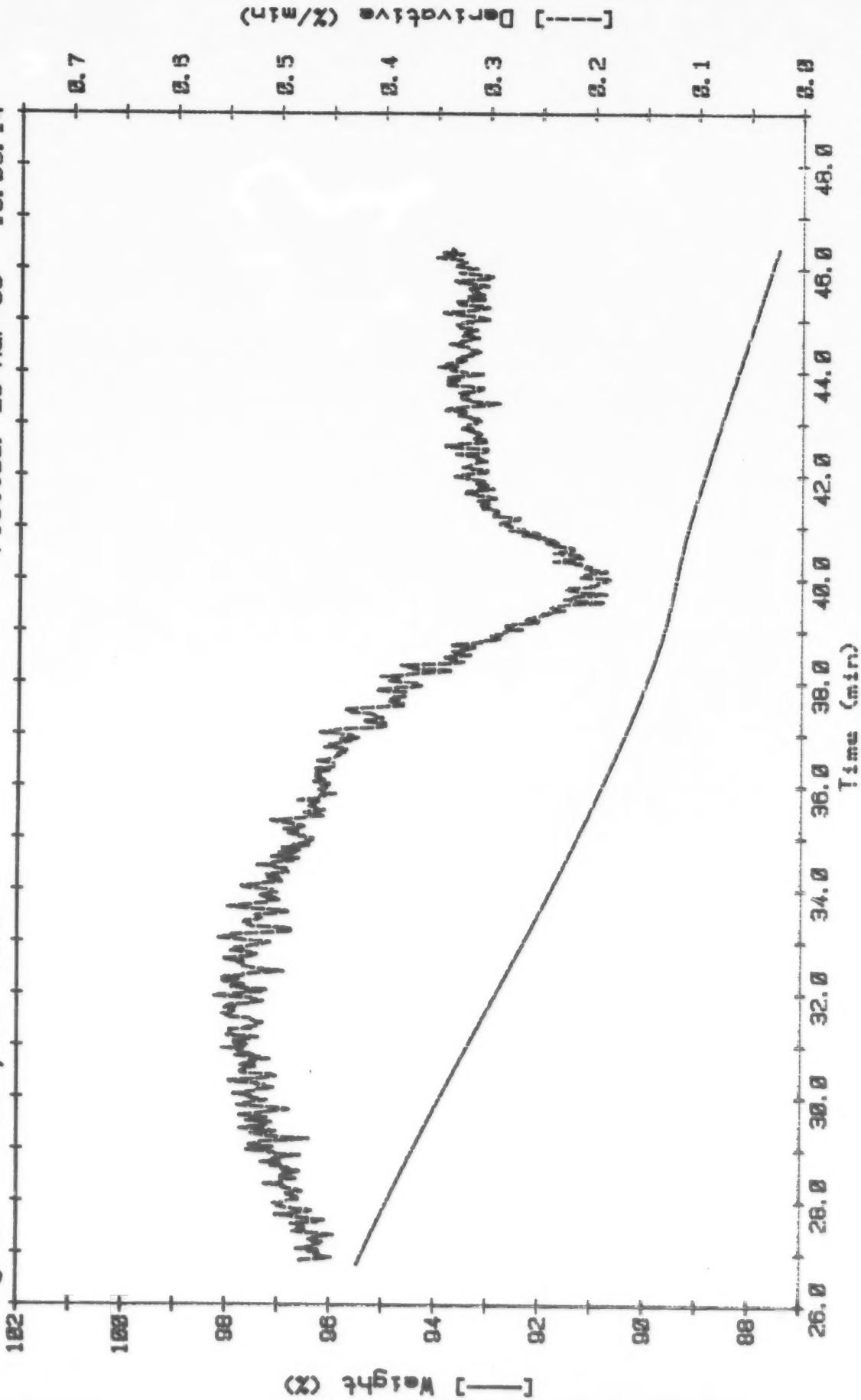
TGA

Date: 26-Feb-85 Time: 9:38:54

File: K+P.04 MISC TEST XII

Operator: ERIN

Plotted: 26-Mar-85 13:08:14



DuPont 1090

Sample: K+P 3-2

Size: 46.62 mg

Rate: 2+15 DEG/MIN IN N2

Program: TGA Analysis V1.0

TGA

Date: 26-Feb-85 Time: 9:38:54

File: K+P.04 MISC TEST XII

Operator: ERIN

Plotted: 26-Mar-85 12:59:43

